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Optimizing Centralized Inventory Systems Using Lateral Transshipments

Elleuch Fadwa
https://orcid.org/0009-0007-6705-7668
University of Sfax, Tunisia

ABSTRACT

This study explores the optimization of centralized inventory systems through lateral transshipments, addressing supply chain disruptions caused by unpredictable demand. Lateral transshipments, which involve reallocating stock among retailers at the same distribution level, were investigated as a cost-effective and service-enhancing alternative to traditional emergency restocking methods. Using simulation and optimization techniques, we analyzed various transshipment policies, including Complete-Pooling and Partial-Pooling, across multiple scenarios. Our findings highlight that Partial-Pooling with an optimized threshold outperformed other policies by balancing collaboration and efficiency, reducing total costs, and improving service levels. The results underscore the importance of hybrid transshipment strategies, particularly for high-demand and cost-sensitive inventory systems. The research provides actionable insights for supply chain managers how tailored transshipment policies enhance centralized system overall supply chain resilience, profitability, and customer satisfaction.

KEYWORDS

Sustainable Supply Chain, Artificial Intelligence, Sustainable Logistics, Supply Chain, Safran Tunisia

1. INTRODUCTION

Effective supply chain management (SCM) is currently identified as a key determinant of competitiveness and success for most manufacturing and retail organizations, because the execution of supply chain management has a significant impact on cost and service level. SCM aims to control the entire flow of a supply chain (physical flow, information flow and financial flow). In this paper we are mainly focused on the management of physical flows in the supply chain. Currently, many quantitative models have been proposed to provide decision support for the management of materials in a supply chain. The overall execution of the distribution network, whether evaluated in economic terms or in terms of customer service, can be significantly improved if retailers collaborate in the event of unexpectedly high demand, which may result in shortages in one or more retail outlets.

Collaboration usually takes the form of "Transshipment - lateral" or also simply "Transshipment", which serves to pool stocks to overcome uncertainties in demand arriving at sites at the same level, and thus to obtain effects similar to those of inventory consolidation. Transshipment can also generate additional service flexibility. Note that, for the same service rate, transshipment is generally significantly less expensive than an emergency order from a supplier if the lateral sites are located nearby.

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For this work will be carried out, in section 5 we have applied the two-step resolution methodology. Then, section 6 presents the results found by applying the simulation and optimization approach obtained. Finally, the conclusion is made in section 7.

2. BACKGROUND AND LITERATURE OVERVIEW

2.1. Transshipment Approaches

First, we distinguish between two approaches to transshipment. The first approach is the emergency transshipment. For this approach, taking into account the dynamic effect of emergency lateral transshipmen within a supply chain.

It tests different strategies to improve customer service. Four distinct strategies are considered. "Electronic points of sale", where market information is transmitted to all actors along the supply chain; where stock levels in the echelons are controlled by the factory; "emergency transshipment", where an express transport route passing through a echelon in the supply chain is authorized.

This approach corresponds to the transshipment carried out after the realization of an actual stock shortage at one or more retailers resulting from the arrival of a demand. In the literature several researchers aim to study this approach. The research work of (Zhang et al., 2001) has analyzed this approach of transshipment-lateral.

The second approach is that of preventive transshipments; these correspond to occur when retailers adjust and balance their stocks or prevent future stockouts. Among the works that are interested in studying this approach, we can cite for example that of (Hu el al., (2007)).

In the literature, the works that have studied emergency transshipment are the most frequent, for this we summarize, in the following paragraph, the policies adopted in this context.

Paterson et *al*., (2012) investigated the problem of a multi-level stock system composed of N- retailers, in the event of an actual retail outage due to a random customer demand arrival. They proposed a reactive approach to solve this problem.

Reyes et *al*., (2013) have studied the same problem as Paterson et *al*., (2012) by focusing their research work on the impact of emergency transshipment on inventory management in this system in case of an actual stock-out, and they concluded that responsive transshipment can reduce costs and improve service r.ates by minimizing the amount of customer order lost.

Kim and Sarkar, (2017) proposed that time is one of the crucial elements of competition, customers get impatient and less tolerant of back orders. Partially unsatisfied orders are a common phenomenon in the retail trade. It has an obvious effect on the corrective transshipment performance because the latter is executed at the end of the sales season in the event of a stock shortage.

Dehghani and Abbasi (2018) considered an aged-based lateral shipment policy for the case of perishable items. They targeted the transshipment of blood units between hospitals. They developed partial differential equations to derive and solve a joint distribution problem that allowed them to determine the optimal inventory level at each location with transshipment based on the age of stock. They also showed that their approach could bring additional savings to a similarly structured distribution channel.

Yi et *al.,* (2020) studie optimal lateral transshipment and replenishment decisions under a decentralized setting. We construct a multi-stage stochastic model that captures demand uncertainty and customer switching behavior. We demonstrate that, similar to the centralized setting, the optimal transshipment decision follows a double-threshold structure.

The second approach is that of proactive (or so-called proactive) transshipment, which is a redistribution of stocks at the beginning or end of each supply cycle but before customer demand is realized.

There is a vast literature that is interested in this type of transshipment approach. Preventive transshipment research is dominated by periodic review, because at the beginning and end of each period it is necessary to periodically check the quantities stored to attribute a redistribution of these quantities. In this regard, Agrawal et *al.,* (2004) envisioned a two-step inventory system in which they aimed to rebalance the quantity stored at a predetermined time before the demand was made and they presented a formulation dynamic programming to determine the best decisions. Van et al. (2009) studied the problem of a two-tier stock system. They applied the Markov process to solve it by applying preventive transshipment on a specific date. Paterson et *al.,* (2010) analyzed a multi-warehouse inventory system that follows inventory policy (S-1, S) combined with the proactive transshipment policy. They assumed that the cost of transshipment is fixed, and they aimed to set the optimal time of the redistribution of stock to minimize the breakage, which entails a minimization of the global cost.

Some research projects have studied the inventory problem with preventive transshipment in a decentralized system. Li et *al.,* (2013) analyzed an inventory system with two storage depots which uses proactive transshipment as an approach to deal with the gap between demand and supply. A bidirectional an income sharing contract has been proposed to coordinate the transhipment quantities between the two entropots. Abouee-Mehrizi et *al.,*(2015) proposed a proactive transshipment model to minimize the mismatch between supply and request. They considered a multi-period inventory with a finite horizon system for two locations and optimal determination of joint replenishment and transhipment policies.

Dan et *al.,*(2016) developed a two-period order and pricing model with preventive transshipment and conditional return. To reduce the imbalance within the system, the manufacturer controlled preventive transshipment between two independent retailers.

Feng et *al*., (2017) addressed the problem of the stock system by applying preventive transshipment. A heuristic combined with dynamic programming algorithms has been proposed to solve the problem. They proposed a non-linear model for a supply chain with transshipment between buyers who had limited warehouse capacity. They have resulted that transshipment increased the rate of use of storage capacity.

Meissner and Senicheva, (2018) studied a multi-site, multi-period storage system with proactive (preventive) transshipment and approximate dynamic programming used determine an optimal order policy and transshipment policy.

To significantly improve a purely reactive transshipment policy, it would be possible to combine it with another proactive policy; this will be named by “Hybrid transshipment policy”.

Glazebrook et *al.,*(2015) proposed a hybrid lateral transshipment policy such that the transshipment decisions are made when a location faces a shortage that resembles a reactive transshipment policy, however, the quantity of transshipment can exceed the current shortage to avoid future imbalance in the inventory system. They employed dynamic programming to solve their model, using a heuristic to approximate the future cost of a decision.

Dijkstra et *al.* (2019) consider the case that the return products ordered online at any offline store may result in unbalanced inventories. To deal with these unbalanced inventories, they study the optimal transshipment policy and prove that it can reduce the cost.

2.2. Transshipment Policies

In this section, we study transshipment policies:

- Partial-Pooling: transshipment is performed by maintaining a targeted stock level.
- Complete-Pooling: the retailer agrees to transfer all of its available stock when needed; in other words, it agrees to pool all of its stock, without restriction (Glazebrook et *al.,*(2015)) explicitly consider that replenishment takes into account lead times and analyzes several transshipment policies by simulation to conclude that “Complete-Pooling” is the best transshipment policy solution.

Depending on the cost parameters, a “Complete-Pooling” policy turns out to be suboptimal in some cases. If, for example, a stocking point has only one part left in stock, it may be advantageous to hold it when requesting Transshipment-Lateral, for some or all demand classes. This situation can occur when the cost parameters for the stocking points and all demand classes are equal (i.e. symmetrical), but its effect can be even greater in the case of asymmetrical cost parameters.

2.3. Transshipment Direction Nature

The literature on unidirectional transshipment for a supply chain is, however, scarce. Seifert et*al*.,(2006) studied unidirectional transshipment integrating direct and indirect sales channels through a traditional retail store and a decentralized virtual store. They analyze how the supply chain of a single manufacturer and several identical retail stores can be coordinated by taking into account a combination of wholesale prices, inventory subsidies and transfer payments. Dong et*al*., (2012) studied a multi-level framework considering a contract manufacturer and two inventory locations which differ in scale and scope such that transshipments are performed only unidirectional to analyse information asymmetry within the context of transshipments. He et*al*., (2014) studied a dual channel supply chain with unidirectional transshipment policies between retailer and manufacturer under endogenous and exogenous transshipment prices. The setting in both papers is somewhat different to our horizontal setting as they consider unidirectional transshipments between different echelons.

Toyasaki et *al*., (2017) considered bidirectional and unidirectional transshipment of relief items in a decentralised humanitarian supply chain under correlated demands. However, since they consider a supply chain network in the non-commercial setting, their model shows significant differences to the commercial setting in terms of cost and price parameters. But, in centralized systems, most publications focused on bidirectional transshipment in supply chains.

This work assumes that transshipment is mutually beneficial for all retailers and object to maximize the global profit of the system and no longer of such a retailer.

Rudi and *al.,* (2001) show that the decentralised system can be coordinated by appropriately set transshipment prices. However, Hu et*al.,* (2007) provide examples which show that such coordinating prices may not exist in several cases. Especially with increasing asymmetries in the economic parameters for the two locations, coordination of bidirectional transshipments may not be possible by varying the transshipment prices. Li et*al.,*(2013) discuss the coordination problem of preventive bidirectional lateral transshipments between two independent locations and propose a bidirectional revenue sharing contract to coordinate the system.

Park et *al.,* (2016) extend the transshipment models of Rudi et*al.,* (2001) and Hu et*al*., (2007) by considering uncertain capacity of the supplier. They find that the sufficient condition for the existence of coordinating transshipment prices is more restrictive under supply capacity uncertainty and limitation than in the case of infinite capacity.

Li and Li, (2017) discussed the impact of bargaining power in a two-tier supply chain consisting of a manufacturer and two symmetrical retailers with bidirectional transhipment between them.

2.4. Nature of Product and Disruption of Demand

Most research work focuses on policies (No Pooling) and (Complete Pooling). For the first policy of transshipment, we cite some research (Guan and Zhao, 2010, Glock, 2012) and for the second policy of transshipment, we give as example (Bouma et *al.,* 2014).

First, we are interested in the problem of transsipment cooperated with the stock management policy (R, S).

In this field, at the end of each basic period, the stock is evaluated, the possible emergency transshipments are then carried out simultaneously and a supply order is placed if it is a revision period. This work generally adopts the deferred claims hypothesis. Recall that the policy (R, S) is particularly appropriate under the assumption of negligible command / setup costs.

Examples of work emphasizing the importance of politics (R, S), Banerjee et *al*., (2003) and Burton and Banerjee, (2005), which focused on the evaluation, by the and 2, 4, and 8 retailer site configurations, the benefits of policy-based transshipment (Complete-Pooling), and those of preventive transshipment.

The research of Herer et *al*., (2004)) focuses on the study of a stock system composed by multi-retailers that are not identical in terms of costs, without constraints of carrying capacity to achieve a reactive transshipment. The random demands arriving at the warehouses are supposed to be correlated (the demands are independent, identically distributed (*i.i.d*)).

The work of Özdemir et *al.,* (2006)) focused on the research of (Herer et *al*., 2004) considering transport capacity constraints according to which the transshipment quantities between deposits located at the same level are limited by the capacity of the means of transport. These researchers have developed an effective stochastic approximative approach using Monte Carlo simulation. The numerical results show that transport capacity constraints increase the global cost as well as alter the distribution of inventory throughout the network.

The same problem studied by (Özdemir et *al.,* (2006)) was also treated by (Ekren and Sunderesh, (2008)) applying the simulation-optimization method of resolution. The optimization procedure is performed by the OptQuest of the ARENA ® software.

Hu et *al.,* (2007) studied a storage system consisting of two retailers and they focused on emphasizing the non-coordination of transshipment prices.

Archibald et *al*., (2009), for their part studied a model composed of multi-retailers not identical in terms of costs, without constraints of transport capacity to achieve a transshipment. The demands arriving at the sites follow the fish law (the demands are independent, identically distributed (*i.i.d*)). To solve this problem they use Markovian resolution methodology.

Pazhani et *al*., (2015) focused in their research work on reducing the global cost of the storage system by minimizing the cost of disruption (minimizing the service rate) and transportation costs, and reducing the cost of transportation. improving the efficiency of the supply chain by making the best decision by selecting the optimal supplier under a stochastic demand constraint.

Second, we focus on the relationship between transshipment with stock management policy (s, Q)

About this, for work that has adopted the continuous revision policy, the system (s, Q) is the most commonly used because it is relatively simple. Investigations have been conducted under the two assumptions of lost-demand systems and delayed-demand systems.

Evers (2001), developed two heuristics to determine the conditions in which transshipments generate benefits for the stock system.

The first heuristic seeks to solve the problem of the transshipment of a single unit and the second addresses the transshipment of multiple units (multiple sites). The all-or-nothing transshipment policy is adopted in the (Evers (2001)) model with a linear transshipment cost, depending solely on the quantity transferred.

The research (Minner et *al.,* (2006)) focuses on a relaxation of the hypotheses of (Evers, (2001)) by accepting transshipments by quantities lower than those demanded and by adding a fixed cost per satisfied query. They also completed the model by taking into account the cost of supply as well as any possible costs of disruption as a result of the transshipment decision.

Satyendra and Venkata, (2005) studied a storage system (s, Q) composed by two-retailers assuming that the demand is random and follows the Normal N law (for that they applied the method of resolution by Simulation for search for the best solution in terms of global cost and rate of service Olssen (2009, 2010) was interested in solving the problem of "unidirectional lateral transshipment" in (s, Q) or (S -1, S) with deferred or lost demands.

Olssen (2015) studied a storage system (s, Q) composed of a distribution center and two retailers, he applied the analytical resolution method to find the optimal solution by applying the policy of transshipment (Partial Pooling).

We focus- on the cooperation between the problem of transshipment with the stock management policy (S-1, S). In this context, the study by (Wong et *al*., (2005)), is one of the few to have assumed that the time of non-negligible transshipment and a delayed transshipment (ie in case of rupture at a warehouse, if no deposit has stock available so the transshipment is delayed (put on hold) until the stock becomes positive in one of the storage sites).

Liu and Lee (2007) focused their research on a single-level, multi-product and multi-retail stock system. They emphasized the influence of partial transshipment on reducing global cost by applying the Markovian method of resolution.

Paterson, et *al.,* (2012) analyzed an inventory system consisting of a single-level, single-product and two-retailers. They demonstrated the importance of making a decision to make the transshipment only if the stock position is above a set threshold. To solve this problem, he applies the analytical resolution method.

Seidscher and Minner, (2013) examined policy (S-1, S) in a stock system composed of a distribution center and N-Retailers, to determine an optimal trans-shipment policy, they applied, first Instead, the policy reacts to minimize the out-of-stock rate, but they deduce that the amount of unsatisfied order is high. For this, they have combined this policy of transshipment with another proactive, which results in an efficient improvement of the optimal result in terms of cost and rate of service.

Patriarca et *al.,* (2016) studied a two-tier stock system, the first includes a distribution center and a maintenance department for repairable parts. The second echelon contains a large number of retailers. First, they applied Complete-Pooling when using transshipment, then they set a threshold beyond which they would make the decision to apply such transshipment.

Finally, we aim to study the transshipment problem with stock management policies (s, S) and (R, s, S).

In this area, the study of transshipment for stock systems (s, S) or (R, s, S) has given rise to relatively less work, probably because of its more complex nature.

Hu et *al*., (2005) examined the policy (R, s, S) in a stock system composed of a distribution center and multiple-retailers with centralized stock management at the distribution center level to improve the overall performance of the system whole. The assumptions considered in their model are very restrictive: zero supply and transshipment times, identical demand parameters, identical costs and infinite time horizon. In this framework, the authors proposed a dynamic programming approach to find the approximate optimal policy (s, S) of the entire system at the distribution center level.

Tlili et *al*., (2010) examined the policy (R, s, S) in a two-step inventory system, the first contains a distribution center with infinite storage capacity and the second composed of multi-retailers. Their research aimed to reason the benefits of complete-pooling and those of partial-pooling on cost reduction. To solve this problem, they applied the “Simulation-Optimization” resolution method and they showed that “partial-pooling” is more efficient than “complete-pooling”, because with a partial transshipment, there remains such a quantity in deposit in overstock position, which may reduce the amount of order lost; this will improve the optimal result in terms of global cost and service rate by reducing the unsatisfied amount of customer demand.

Previous works have tended to assume that the demand function is linearly dependent on variables such as retail price or promotion cost, and that the constant term of the function, which is usually referred to as the initial market share, is disrupted by a variation (Shen and Li, 2016). We argue that the conventional technique of modeling a demand disruption is not suitable for characterizing disruption of stochastic demands. The conventional characterization of demand disruption is to assume there is an additive variation on the experienced demand value Shen and Li, (2016). However, when a demand is stochastic, it is hard to recognize whether an additive difference between the materialized demand value and the experienced demand value is due to the demand disruption or the essential uncertainty of the stochastic demand. So it is necessary to develop an alternative method to characterize the disruption of stochastic demands. In addition, in the presence of today's economic globalization, consumer demands are becoming even more unstable since they can be disrupted very frequently, and even continuously (Grossman, 2016; Wolcott, 2016). This fact requires that the desirable characterization of disruption of stochastic demand should not only give the disrupted value bias between materialized value and the experienced value, but also reflect the decreasing systemic stability.

Xiao and Shi (2016) examined the problem of dual channel SC coordination where the manufacturer's production process works to a random yield rate. Since in this situation shortages are common, optimal decisions and coordination in SC are significant.

They proposed two priority strategies to optimize decision variables.

Ji et *al*., (2017) considered demand disruption in a two-stage supply chain from the manufacturer to the retailer and then to the consumer, with a transshipment-before-buyback contract. This contract was also investigated for a supply chain of two retailers and a manufacturer and showed that it was beneficial for all parties to enter this contract. Their results also showed that a predetermined or negotiated transshipment price could benefit all parties where there is a disruption in demand and that a buyback guarantee does not influence transshipment price despite a manufacturer's incentive.

3. INTEGRATION OF “DATA ANALYTICS AND ARTIFICIAL INTELLIGENCE (AI)” IN TRANSSHIPMENT-LATÉRALE

Data analytics and artificial intelligence (AI) are two interconnected fields that are transforming the modern technology landscape. AI uses advanced algorithms to process, interpret, and draw meaningful conclusions from large data sets. This article explores the synergies between these disciplines and their implications for various industries.

Data analytics is the process of collecting, cleaning, and examining data to extract useful information. With the explosion of data in the digital age, this discipline has become crucial. Businesses can make informed decisions, optimize operations, and personalize services based on consumer behaviors.

Artificial intelligence, on the other hand, focuses on creating systems that can perform tasks that typically require human intelligence. This includes speech recognition, computer vision, and machine learning. AI can automate data analysis processes, accelerating decision-making and identifying patterns in information (Mustak et al., 2021).

Integrating AI into data analytics can improve the efficiency and accuracy of analytics. For example:

- AI-based predictive models can analyze past trends to predict future outcomes in areas such as marketing and finance.
- Classification algorithms, such as decision trees and neural networks, help categorize complex data quickly and with high accuracy.
- AI allows businesses to analyze user behavior to provide personalized recommendations, increasing customer satisfaction.

Data analytics and artificial intelligence are a powerful duo that are revolutionizing the way information is processed and used. As these technologies continue to evolve, they promise to create new opportunities and address challenges across many industries. To maximize these benefits, it is essential that businesses invest in data science and AI skills, ensuring their competitiveness in an increasingly data-driven world.

Data analytics plays a crucial role in modern supply chain management, especially when it comes to lateral transhipment. This process, where goods are transferred from one means of transport to another without entering a warehouse, requires a deep understanding of data flows to optimize efficiency and reduce costs.

Data analytics helps identify trends and patterns in logistics behavior. By using advanced analytics tools, companies can:

- Predictive models help estimate the quantity of goods required at different times of the year, minimizing the risk of overstocking or stockouts.
- Optimization algorithms can determine the most efficient paths for transportation, reducing the time and costs associated with transhipment.
- With better data visibility, companies can track the progress of goods in real time, which is essential for efficient transhipment.

Lateral transshipment refers to the practice of transferring cargo from one vessel to another or from one means of land transport to another at an intermediate point.

Benefits include:

- By avoiding warehouses, products can be transported to their final destination more quickly.
- Companies can quickly adapt to changes in demand and unforeseen circumstances.
- Less warehousing means less overhead and reduced operational costs.

Integrating data analytics with lateral transshipment strategies offers immense potential to improve logistics efficiency. By investing in powerful analytics tools, companies can not only optimize their operations but also anticipate market challenges. In doing so, they position themselves favorably in an increasingly competitive business environment.

4. THE IMPACT OF LATERAL TRANSLOADING ON SERVICE LEVELS, CUSTOMER SATISFACTION, AND SUPPLY CHAIN RESILIENCE

In a globalized economy, lateral transloading is emerging as a critical logistics strategy. This process, which involves transferring goods from one means of transport to another without storing them, can have a significant impact on service levels, customer satisfaction, and supply chain resilience (Mishra et Tripathi, 2021).

Lateral transloading directly impacts the service levels of a supply chain. By enabling more efficient management of the flow of goods, it reduces delivery times. This allows suppliers to respond quickly to customer requests, which is crucial in speed-critical environments. In addition, this method offers flexibility, making it possible to adapt to unforeseen events, such as changes in demand or transportation interruptions (Barazandeh and Ghazanfari, 2021).

Customer satisfaction largely depends on a company's ability to deliver its products on time and ensure delivery reliability. Lateral transloading, by optimizing routes and minimizing waiting times, helps improve the customer experience. Studies show that companies that effectively integrate lateral transloading strategies achieve higher customer satisfaction rates, as they can reduce incidents of delays and offer better order tracking (Alamin, et *al*. 2022).

Another important aspect of lateral transloading is its ability to strengthen the resilience of supply chains. By diversifying transportation options and enabling rapid alternatives in the event of disruptions (such as strikes, natural disasters or congestion), companies can maintain a continuous flow of goods. The flexibility of lateral transloading also allows for rapid response to market fluctuations, minimizing the impact of potential crises (Alfaroet *al*., 2023)

In short, lateral transloading is a strategic lever for improving service levels, increasing customer satisfaction and strengthening the resilience of supply chains. As companies seek to adapt to contemporary challenges, integrating this method into their logistics operations could well be the key to their future success. By investing in the right infrastructure and technology, companies can maximise the benefits of lateral transloading, positioning themselves as market leaders.

Artificial intelligence (AI) is playing an increasing role in the field of lateral transhipment, particularly in ports and logistics centers, where goods need to be transferred between different modes of transport (e.g. between ships, trucks, trains, etc.). The impact of AI in this field is evident in several ways:

First, AI can analyze real-time data to optimize routes, dock management, and the distribution of human and material resources. This improves the fluidity of the transhipment process, reducing waiting times and increasing the overall efficiency of operations.

It enables the development and optimization of autonomous vehicles (such as forklifts, transport robots, and container handlers) and other automated systems to move goods between different means of transport. These systems can operate 24 hours a day, reducing human error and increasing productivity.

Also, thanks to AI, it is possible to predict the storage, space and resource requirements for each stage of the transshipment process. This improves the planning of goods flows and inventory management, minimizing the risks of congestion or resource shortages.

Secondly, AI can predict potential failures of equipment used in lateral transshipment (such as cranes, conveyors or automated vehicles), thus enabling preventive maintenance. This avoids unplanned downtime and contributes to business continuity.

Finally, it can analyze large amounts of data from different sources (cameras, sensors, ERP, etc.) to identify trends, inefficiencies or recurring problems. This information can be used to make more informed decisions and adjust transshipment management strategies.

In short, integrating AI into lateral transloading helps improve efficiency, reduce operational costs, increase safety and provide greater flexibility in the face of fluctuations in demand.

Lateral transloading is a key strategy used to optimize inventory systems in supply chain management. This method involves moving products directly from one transportation vehicle to another, often bypassing the storage stage in a warehouse. For supply chain managers, here are some specific strategies they can implement to maximize the benefits of lateral transloading: First, organize the flow of goods so that they arrive and depart quickly, minimizing storage times in transloading areas.

Coordinate with suppliers and carriers: Ensure that deliveries arrive at times when there is sufficient capacity in the transloading docks and that carriers are ready to depart immediately after unloading their cargo (Babina et al. 2023).

Then, improve real-time data management by using RFID technology or real-time inventory management systems: This helps track products as they move through the cross-docking process and ensures that inventory is continuously updated.

Then, integrate robust warehouse management systems to improve inventory visibility, making it easier to sort and move products faster.

Finally, the manager applies optimal cross-docking space layout, ensuring that facilities are designed for fast, unobstructed flow, by setting up distinct receiving, sorting, and shipping areas.

Finally, he prioritizes high-demand products and identifies fast-moving items and places them in strategic cross-docking areas to reduce processing times.

Using a Just-in-Time (JIT) Model: Implementing inventory management that relies on frequent but reduced replenishments to maintain low inventory levels and reduce storage costs (Goldberg and Pinelopi Koujianou. 2023).

By incorporating these strategies, supply chain managers can not only optimize their inventory system, but also improve the overall efficiency of the logistics process, reduce costs, and increase customer satisfaction.

Lateral cross-docking (or cross-docking between different points in the supply chain) can play an important role in optimizing inventory systems by enabling smoother and more responsive inventory management. Here are some specific strategies that supply chain managers can implement to leverage lateral cross-docking for this purpose:

First, use a real-time inventory management systems, such as warehouse management software (WMS), which allow managers to instantly track and visualize inventory levels across multiple warehouses or locations.

This helps identify inventory imbalances and make quick decisions to move excess inventory from one location to another.

Then, managers can use lateral cross-docking to adjust inventory levels across different warehouses or distribution points based on actual needs, reducing the risk of stockouts or overstocking.

This helps to better meet customer demand while minimizing the costs associated with excess inventory.

Additionally, by distributing inventory more dynamically and flexibly across locations, managers can optimize the use of storage space by moving excess inventory to locations where space is more available or less expensive.

This helps minimize warehousing and inventory management costs, especially if different warehouses have varying storage costs.

Then, lateral transloads can be used to streamline transportation costs by consolidating smaller shipments and optimizing delivery routes, thereby reducing freight costs.

For example, if Warehouse A has excess inventory and Location B is understocked, it may be more cost-effective to do a lateral transload between the two, rather than going through an external supplier.

Additionally, by proactively reorganizing inventory through lateral transloads, managers can reduce customer delivery times by moving products closer to high-demand areas, without having to wait for external replenishments.

This improves customer service and allows for faster response to fluctuations in demand.

Also, lateral transloads can be coupled with advanced demand forecasting tools, allowing inventory to be moved between locations in advance to avoid shortages or surpluses.

Forecasts can be adjusted based on local consumption trends, and inventory can be moved accordingly before shortages or overstocking issues arise.

Finally, establishing clear and effective communication between different warehouses, suppliers, and carriers is essential for lateral transloads to run smoothly.

Joint planning and inventory management based on the specific needs of each site or region can contribute to better overall inventory optimization.

And, integrating robotics into warehouses and inventory management can speed up lateral cross-docking processes, reducing the time it takes to move products from one location to another.

For example, autonomous vehicles or drones can be used to transport inventory between different warehouses or storage areas, minimizing human error and improving the speed of transfers.

Lateral cross-docking, when used strategically, can make inventory systems more flexible, responsive, and cost-effective. By optimizing inventory movements between locations and improving inventory visibility, supply chain managers can better manage inventory levels, reduce costs, and improve customer satisfaction.

5. PAST LITERATURE ASSESSMENT

The interplay of transshipment strategies with inventory management policies - ranging from (R, S) to (s, Q) - has been widely studied. Each policy offers distinct advantages depending on demand patterns, cost structures, and operational constraints. Further exploration of hybrid and proactive strategies may offer innovative solutions to these ongoing supply chain challenges. Additional case studies and simulations like presented in this study are also needed.

Due to the complexity involved in analytical modeling, particularly because the demand distribution is random, the stock position for each retailer becomes unknown and difficult to calculate. This challenge led us to adopt a "Discrete Event Simulation" (DES) approach. This method allowed us to relax the restrictive assumptions inherent in the mathematical model and to analyze, in greater detail, the contributions of transshipment and its sensitivity to various parameters, such as periodicity ("T"), threshold, and unit cost of transshipment.

The primary objective of a discrete event simulation study is to model and analyze the behavior of physical systems - sets of entities interacting over time - whose states evolve dynamically. For example, in systems like computer networks, DES enables the identification of operational parameters to measure and improve system performance.

In our research, we employed metamodel-based search methods. An optimization strategy based on metamodels is particularly aimed at constructing modeling languages, establishing relationships between models, and defining modeling rules.

6. DESIRABILITY FUNCTION APPROACH

The desirability function approach evaluates how well a combination of variables meets specific objectives. It uses two metrics: individual desirability (d), which measures the optimization of a single response, and composite desirability (D), which assesses the overall optimization of multiple responses. Desirability ranges from zero to one, where one represents the ideal outcome, and zero indicates that one or more responses are outside the acceptable range.

The desirability approach involves the following steps:

1. Conduct experiments and fit response models for all (k) responses.
2. Define individual desirability functions for each response.
3. Maximize the overall desirability (D) with respect to controllable factors.

Response optimization identifies the combination of variable settings that optimize a single response or a set of responses. This process is particularly useful when evaluating the impact of multiple variable on a response.

Before using response optimization, a model must be fitted for each response. For optimizing multiple responses, individual models are required. Notably, response optimization does not utilize raw data from the worksheet. Instead, software like Minitab retrieves stored models to extract the necessary information.

To define a desirability function, values are assigned to the responses to reflect their desirability. The multi-objective desirability optimization method involves transforming each predicted response $\hat{y}$ into a partial desirability function $\boldsymbol{d}_i$. This transformation incorporates the researcher's priorities and preferences, as outlined in Equation (1).

$$\mathbf{d}_{\mathbf{i}\,=}\left(\frac{\hat{y}-A}{B-A}\right)w_i\,\mathbf{if}\ \mathbf{A}\leq\hat{y}\leq\mathbf{B}$$

$$\boldsymbol{d}_{i=1}\ \boldsymbol{if}\ \hat{y}\ \geq\ B \qquad (1)$$

$$\mathbf{d}_{\mathbf{i=0}}\ \mathbf{if}\hat{y}\leq\mathbf{A}$$

In Equation (1), ***A*** and ***B*** are, respectively, the lowest and the highest values obtained for the response ***i***, and w_i is the weight. It is obvious that di ranges between **0** and **1**. Individual desirability and composite desirability measure how well a combination of variables meets the objectives you set for the responses. Individual desirability (d_i) measures how well the parameters optimize a single response, while composite desirability (**D**) measures how well the parameters optimize a set of responses overall. Desirability ranges from zero to one. One represents the ideal case; zero indicates that one or more responses are outside the acceptable range, as shown in Equation (2).

$$D\ =\ \left(\prod_{i=1}^{n}d_i\right)^{\frac{1}{n}} \qquad (2)$$

If the value of **D** is close to **1**, it indicates that the results obtained are favorable for all responses as a whole. Minitab's response optimization calculates individual desirability using a desirability function (also called a utility transfer function). This will be applied to find the optimal values $\mathbf{s_i}$ and $\mathbf{S_i}$ of the periodic replenishment policy ($\mathbf{T, s_i, S_i}$), with $\mathbf{T=1}$.

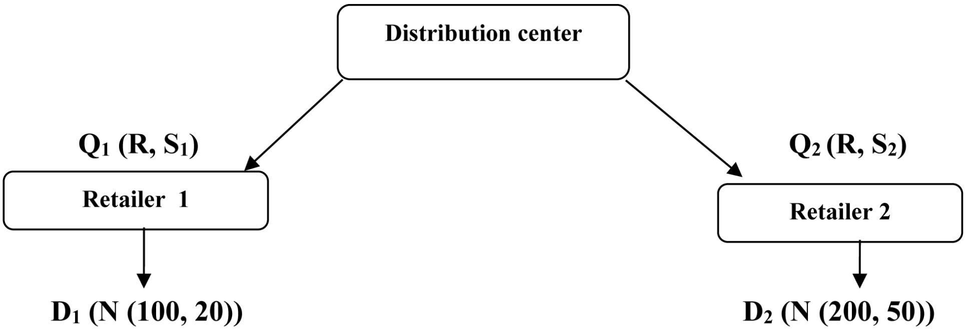
6.1. "No-Transshipment" Case

6.1.1. Conceptual Model

In this case, if the retailer is faced with a random demand and to satisfy it and does not run out of stock, it must claim the missing quantity from the central warehouse.

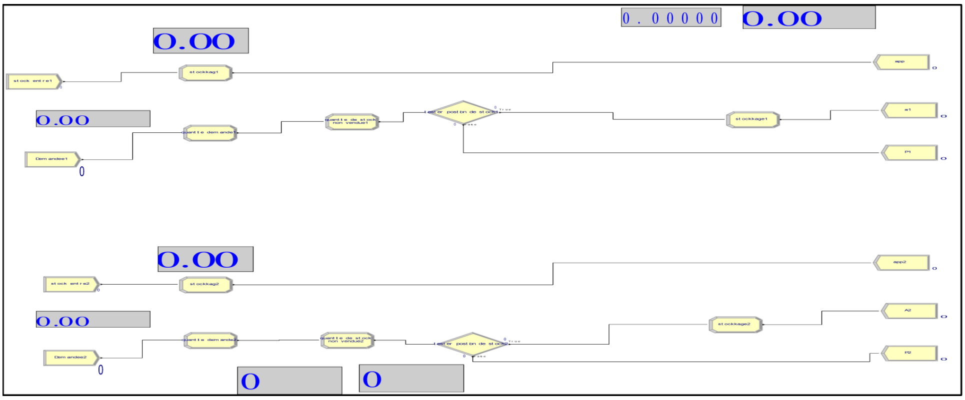
This can be represented by Figure 1.

Figure 1. Two-retailer "no-transshipment" inventory distribution system



For the « No-Pooling » case, the modeling by the ARENA 16.0 software can be presented in Figure 2.

Figure 2. Le modèle de simulation supply chain: No-pooling



6.2. Assumptions

To properly model this inventory system using Arena software, it is necessary to list the assumptions and operating mode retained in this work:

- The storage capacity of the central warehouse is infinite;
- Retailer i applies the storage policy (R_i, S_i);
- Partial satisfaction of an order is not allowed,
- Any unsatisfied order will be lost;

Only one order (urgent according to the central warehouse) is allowed per supply cycle (at the end of period R); with R = kT

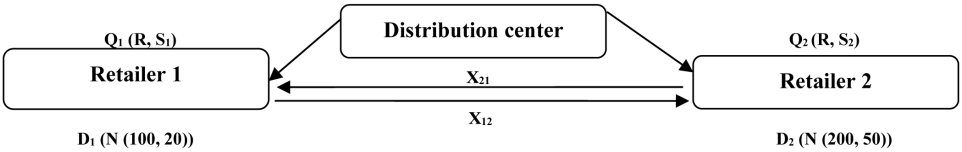
- There is no defined priority order. All customer orders are managed according to the same FCFS (First Coming First Served) priority rule;
- The distribution center has sufficient storage capacity, so as not to introduce availability constraints (Unlimited storage policy);
- At the beginning of each supply cycle, an order of size Q_i (avec $Q_i = S_i - PS$) is placed to reach the inventory level denoted by S_i.

6.3. "With-Transshipment" Case

Conceptual Model

If one of the two retailers is out of stock, cooperation can be established between them to meet their random demand. This collaboration generally takes the form of "Lateral -Transshipment", also simply called "Transshipment" (Figure 3), which allows pooling stocks to overcome uncertainties related to demands arriving at sites of the same level.

Figure 3. Two-retailer "with-transshipment" stock distribution system



7. SOLUTION METHODOLOGY

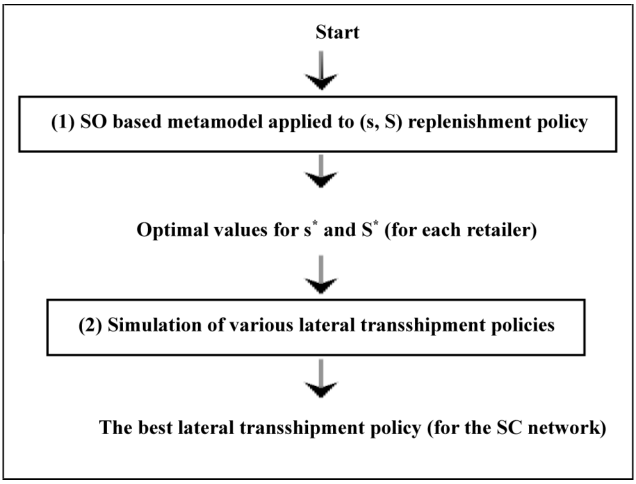
In this paper, we focus on a network composed of two retailers, a single product and a periodic revision type with a replenishment policy **(T, s_i, S_i)**, with **T=1.**

The problem is how to choose the values of $\mathbf{s_i}$ and $\mathbf{S_i}$ of each retailer, and what is the best lateral transshipment policy (Complete-Pooling or Partial-Pooling) that would be implemented.

Our methodology for solving our model is illustrated in Figure 4. First, we focus on the simulation-optimization approach to find the optimal values **(T, s_i, S_i)**, of each retailer i=1,2.

Second, by changing the transshipment policy from "Complete-Pooling" to "Partial-Pooling", we notice such an improvement in terms of overall gain but also following the modification of the threshold parameter of "Partial-Pooling", this influences not only the improvement of the profit but also the minimization of the quantity loss rate.

Figure 4. Methodology for solving the model



Our objective will be to apply a simulation approach to evaluate the impact of different lateral transshipment policies (Complete-Pooling and Partial-Pooling) between two retailers located at the same echelon. Each site applies the periodic review storage policy of type (**1,si*, Si***).

7.1. Assumptions in Modeling

To properly model this inventory system using Arena software, it is necessary to list the assumptions and operating mode retained in this work:

- The storage capacity of the central warehouse is infinite;
- Retailer i applies the storage policy (1, s_i,S_i);
- Partial satisfaction of an order is not allowed,
- Any unsatisfied order will be lost;
- There is no defined priority order. All customer orders are managed according to the same FCFS (First Coming First Served) priority rule;
- The distribution center has sufficient storage capacity, so as not to introduce availability constraints (Unlimited storage policy);
- At the beginning of each supply cycle, an order of size Q_i (avec $Q_i = S_i - PS$) is placed to reach the inventory level denoted by S_i.

7.2. The (s_i*, S_i*) Replenishment Policy Settings

We consider one of the most common practical stochastic inventory control problems, known as the (**T**, s_i, S_i) model with **T=1**. Note that, in this periodic inventory control policy, the two policies (**r, Q**) and (**T, S**) are combined. In fact, at the end of each periodic control period R, we examine the stock position. As shown in Equation (3), we place an order only if this position is below an order threshold denoted r (or s_i). The order quantity aims to bring the stock position back to a replenishment level denoted $\boldsymbol{S_i}$.

$$Q = \begin{cases} S_i - I \; if \, I \leq s_i \\ 0 \; if \, I > s_i \end{cases} \tag{3}$$

The demand at retailer i during a period **T = 1**, is a random variable that follows the normal distribution with mean μ_i and standard deviation σ_i. We assume that the demands at retailers are independent and identically distributed ***(i.i.d*).**

When this demand causes a stock shortage during the control period at retailer 1, a transshipment will be made from retailer **2** to **1**, the transshipped quantity will be noted $\mathbf{X_{21}}$.

We also assume that the transshipment time is zero and that the unit cost of the transshipment is noted **C**. The latter is a linear cost with the quantity transferred between retailers. Finally, we assume that partial satisfaction of customer demand by the retailer is not allowed, and that demands that cannot be satisfied by the available stock and transshipment will be lost and are subject to a shortage cost noted per unit lost. In all cases, the available stock becomes equal to zero and will remain zero until the next supply.

In this article we assume the following:

- Demands are independent and identically distributed and are distributed according to the normal distribution (N (200,50));
- The maximum underservice rate is 0.12l and
- The variable order cost is 3 and the fixed order cost is 57.

7.3. The Tested Transshipment Policies

The “Complete-Pooling” policy is applied if the demand of a retailer cannot be satisfied solely by the transshipment of the other retailer located at the same level, in a way that minimizes the Average Global Disservice levels by increasing the average Global profit of these retailers.

We assume that retailer **1** is the one facing a stock shortage, then according to this transshipment policy, retailer **2** agrees to transfer all of its available stock when needed, even if, this stock is not enough to meet all of the demand of the customer who is the origin of the transshipment request. The transshipment quantity, according to this policy, will be formulated in the form of Equation (4).

$$X_{21} = \begin{cases} D_{1T} - S_1 \, if D_{1T} - S_1 \leq PS_{2T} \\ 0 else \end{cases} \tag{4}$$

In Equation (4), $PS_{2T} = S_2\text{-}D_{2T}$

For the Transshipment-Lateral policy, we assume the following:

- Each retailer **1** is faced with a random stationary demand independent of the demands of site **2**;
- The transshipment time is zero (because the two depots are very close);
- In the case where a retailer 1 faces a stock shortage, while, retailer 2 has a surplus of stock, a transshipment of the necessary quantity will take place from 2 to 1 to avoid or minimize the shortage: this is the corrective transshipment (also called, reactive transshipment). Otherwise warehouse i may require an emergency order of size Q1 to the central warehouse;

In case of “Complete-Pooling”, the retailer who is in an overstock position agrees to transfer all his available stock if needed. Whereas, when “Partial-Pooling” is applied, a targeted stock level is retained.

If the parties involved (e.g. retailers) are independent companies, the question arises what will be their contribution to the pool, and how the pooled units will be allocated if necessary. This can be determined by negotiation.

In this study, fie different scenarios are evaluated: (S1) without transshipment; (S2) complete pooling policy, (S3) partial pooling policy with a threshold level equal to s_i*, (S4) partial pooling policy with a threshold level equal to s_i*/3, and (S5) partial pooling policy with a threshold level equal to s_i*/5.

The demand experienced by a retailer is fulfilled from its existing stock. When the on hand inventory quantity at a retailer reaches its reorder point, a replenishment order is placed. When the on-hand inventory quantity at a retailer reaches its reorder point, the stock level at other retailer is checked. If the stock level of other retailer is more than a predetermined threshold level (the stock level above which the stock can be transferred from one retailer to another retailer), the order is placed on to the other retailer.

7.4. The Main Simulation Model

The Arena simulation software was used to develop the simulation model of the supply network. Arena, developed by Rockwell Automation, is a simulation and automation software based on SIMAN processor and simulation language.

8. EXPERIMENTS, RESULTS, AND DISCUSSIONS

Step 1: Selection of the Optimal (s, S) Replenishment Policy

Before collecting and analyzing the simulation results, it is essential that the steady state is reached. The steady state will be reached only if the variables do not vary with time. In our model, the steady state is reached in less than 500 days.

A test survey is applied in which the factors ($\mathbf{s_i}$ and $\mathbf{S_i}$) supposed to affect the result are systematically modified by modifying each time the transshipment policy and the Partial-Pooling threshold. The results of total cost and Disservice Rate will then be measured and recorded. In this survey, we have chosen, for each variable s and S, two levels. For s, level 1 includes 1000 units and level 2 includes 1500 units. For S, level 1 includes 1500 units and level 2 includes 2500 units. Many simulations have been studied by fixing the duration of each simulation at 500,000 days. The result of these executions is presented in Table I.

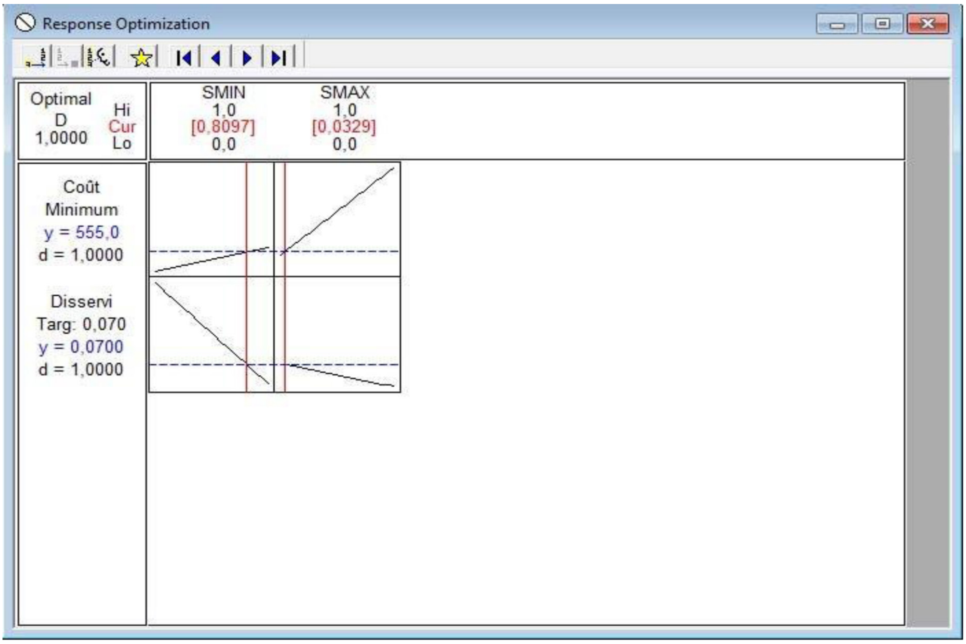
Table 1. The factorial design configurations of the (s, s) replenishment policy

Experiment	Factor levels		Total Inventory Cost	Disservice
	s_i	S_i		
1	1000	1500	326.9	15.9%
2	1500	2500	852.8	6.5%
3	1000	2500	667.9	3.7%
4	1500	2500	860.5	1.9%

After analyzing the experiments by changing the transshipment-lateral policy and identifying the most important factors in the model, which are used as inputs for the optimization of the desirability. This optimization tool is integrated into the Minitab software which has the role of observing current and historical data to detect trends, detect and predict patterns, discover hidden relationships between different variables and create beautiful visualizations in order to overcome the most complex challenges and situations.

By applying Equation (1) for each response measure, we obtain in an optimal configuration that the individual desirability for each performance measure (inventory cost and compensation) is equal to 1. The optimization of the response consists of determining to what extent the solution has achieved the combined objectives for all the responses. The composite desirability for both of these variables is 1. To achieve this desirability, we would set the factor levels to the values shown under the global solution. That is, each retailer would set its si* level to 905 units and its Si* level to 1033 units.

Figure 5. Multi-objective optimization based on desirability functions



Optimal
D
1,0000

SMIN
1,0
[0,8097]
0,0

SMAX
1,0
[0,0329]
0,0

Coût
Minimum
y = 555,0
d = 1,0000

Disservi
Targ: 0,070
y = 0,0700
d = 1,0000

Step 2: Selection of the Best Transshipment Policy

The different configurations of the two Transshipment policies (Complete-Pooling and Partial-Pooling) will be modeled and simulated over a period of 500,000 days. In addition to the earlier assumptions, the following additional assumptions are made in this second step:

- Each retailer ***i*** with ***i=1,2*** uses a storage policy of type ($\mathbf{s_i}$, $\mathbf{S_i}$*), which is optimized in the first step.
- Transshipment times are assumed to be zero.
- The variable unit transshipment cost is 3.

As presented in Table 2, all the lateral transshipment policies are beneficial for the supply chain. In fact, the average global Disservice rate of the two retailers located at the same echelon is lower when the transshipment policy is used and does not exceed 3.7%. The additional cost due to each transshipment policy varies from 8% to 21%. It is worth noting that the most profitable policy of Transshipment-Latéral is that of "Partial-Pooling" by setting a threshold level $\mathbf{s_i}$***** to ($\mathbf{s_i}$***/2**). This experimental analysis shows the importance of Transshipment-Latéral as a tool for cooperation between retailers of the same echelon in supply chains. It seems that the results of this study are obviously valid only within the framework of the specific operating assumptions of the model studied in this research work.

Table 2. Simulation results of the five tested transshipment policies

	(S1) Without transshipment	With transshipment			
		(S2) Complete pooling	Partial pooling		
			(S3) TL is s_i*	(S4) TL is s_i*/2	(S5) TL is s_i*/4
Retailers inventory cost	1207.5	1029.5	1207.5	1064.1	1032.3
Transshipment cost	0	168.3	250.7	207.5	171.9
Total cost	1207.7	1317.6	1338.9	1261.5	1334.9
Disservice	7.65%	3.95%	0.15%	0.13%	0.75%

9. CASE STUDY: LATERAL TRANSSHIPMENT APPLICATION IN TOMORROW MEDIA GROUP

In the dynamic world of media and logistics, the concept of lateral transshipment is gaining more and more importance. Tomorrow Media Group, a leader in the media industry, is positioning itself as a key player in integrating these two fields to optimize content distribution while facilitating economic exchanges.

Lateral transshipment refers to the method of transferring goods or content from one mode of transport to another without stopping at intermediate transit points. This process is becoming essential in a world where speed and efficiency are paramount. In the context of Tomorrow Media Group, this involves the agile transfer of data and digital content across various distribution channels.

Tomorrow Media Group is not only producing innovative content; it is also looking to transform the way that content is delivered and consumed. By integrating lateral transshipment solutions into their operations, they can ensure that information reaches their target audience quickly and efficiently. This not only helps meet tight production deadlines but also adapts to changing consumer preferences.

The Benefits of this Model:

- Through lateral transshipment, Tomorrow Media Group can streamline its operations, reduce costs and minimize delivery times.
- The adaptability of this model allows the company to respond effectively to emerging market trends and customer needs.
- By combining modern logistics with digital content, Tomorrow Media Group fosters an environment of innovation that can translate into a better user experience.

Tomorrow Media Group, through its use of lateral transshipment, demonstrates how the marriage between media and logistics can revolutionize the industry. By adopting cutting-edge methods and staying in tune with the needs of its audience, the company is positioning itself not only as a leader in content creation, but also as a pioneer in optimizing its distribution. This integrated model could well be the key to navigating a future where speed and efficiency reign supreme.

10. CONCLUSION

To achieve our objectives, this work has gone through three stages. The first stage is about developing a transshipment model. The second is based on developing a simulation model of a stock management policy of type (s_i^*, S_i^*) with periodic review. Finally, the third stage is based on the simulation application of different emergency transshipment policies. In addition to the case without transshipment, four other policies were evaluated.

We conclude that the behavior of the stock model with transshipment strongly depends on the choice of the transshipment policy. We explored four different policies, namely: the policy without transshipment, the complete pooling policy, and two partial pooling policies. The first used s_i***/2** and the second s_i***/4**. In the case of the two partial pooling policies, each retailer can control the degree of cooperation by setting a maximum transshipment capacity.

The study identifies Partial-Pooling with an optimized threshold (si*/2) as a particularly effective policy. This approach balances collaboration and efficiency, offering a scalable solution for supply chain managers. The findings bridge critical gaps in decision-making frameworks for transshipment in centralized systems, and thereby provides actionable insights for improving supply chain economic outcomes and service levels.

CONFLICTS OF INTEREST

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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CORRESPONDING AUTHOR

Correspondence should be addressed to Elleuch Fadwa; fadoielleuch5@gmail.com

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