TRANSPORT PROBLEMS 2023 Volume 18 Issue 4
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2023.18.4.14

Keywords: network design; transportation; inventory optimization

Lucas Cedroni FAVA[1], Marcelo Koiti FUGIHARA[2], Mauro SAMPAIO[3*]

SUPPLY CHAIN DESIGN: A CASE STUDY IN A PULP AND PAPER COMPANY

Summary. This paper comprehensively analyzes a company's supply chain design process in the pulp and paper industry. It focuses on the company's supply chain strategy, structure, operations, and performance and highlights the challenges and opportunities specific to the industry. The purpose of this case study is to show how effective supply chain design can improve a company's competitiveness and success. This paper also offers recommendations for improving supply chain design in the pulp and paper industry and other similar industries.

1. INTRODUCTION

A well-designed network and supply chain can improve an organization's ability to respond to market demands, competitiveness, and resource management [1, 2]. Supply chain design analyzes and optimizes various elements, such as suppliers, production, warehousing, and distribution, for greater efficiency and effectiveness. The design should align with the company's overall business strategy and goals, taking into account cost, risk, and responsiveness. [3] highlights that the supply chain model is crucial for a company to gain a competitive advantage, as 80% of the total cost is determined by facility location decisions. [4] Supply chain models encompass tactical (medium-term) and strategic (long-term) decisions.

The design of a supply chain is complex, requiring a thorough analysis of multiple factors, even for minor issues. The number of global facilities a company has must be analyzed in detail. While a greater number of facilities can offer consumers shorter response times and lower outbound transport costs, it also results in higher inventory and inbound transport costs [5]. [6] noted that inventory and transport network levels are the most valued strategic factors when companies determine the locations of their facilities.

The supply chain's importance is significant for both industry practitioners and academics. In the corporate world, an efficient supply chain offers numerous benefits to companies, such as value addition, improved customer satisfaction, inventory reduction, better service quality, and faster product development cycles [7]. From an academic standpoint, studying the supply chain provides a deeper understanding of its essential variables. When designing a supply chain, analyzing demand characteristics is crucial. This analysis helps determine the ideal inventory and production approach for each product in a company's portfolio, whether it's make-to-order or make-to-stock, based on an evaluation of product demand and classification [7].

This study is undertaken with the objective of identifying the most effective supply chain design for a pulp and paper company that caters to North American customers. The research endeavors to address

[1] FEI University; Av. Humberto de Alencar Castelo Branco, 3972-B São Bernardo do Campo - SP, 09850-901, Brazil; e-mail: lucas.cedroni@via.com.br; orcid.org/0000-0002-4011-2133
[2] FEI University; Av. Humberto de Alencar Castelo Branco, 3972-B São Bernardo do Campo - SP, 09850-901, Brazil; e-mail: mfugihara@fei.edu.br; orcid.org/0000-0001-5914-9406
[3] FEI University; Av. Humberto de Alencar Castelo Branco, 3972-B São Bernardo do Campo - SP, 09850-901, Brazil; e-mail: msampaio@fei.edu.br; orcid.org/0000-0002-1217-6295
[*] Corresponding author. E-mail: msampaio@fei.edu.br

inquiries pertaining to the optimal distribution system, inventory policies, and their implications on network configuration.

The study adopts a single case study approach, structured into five distinct sections: introduction, literature review, research methodology, findings and conclusions. The overarching aim is to make a meaningful contribution to the enhancement of supply chain designs within the pulp and paper industry.

2. LITERATURE REVIEW

The literature review examines studies that provide insights into logistics network modeling and information technology for network design, as these areas are crucial for optimizing a company's supply chain. The literature provides a comprehensive understanding of the concepts, models, and tools available to aid the design of an effective and efficient supply chain network.

2.1. Modeling of a logistics network

According to [8], the supply chain design reduces total costs and improves network transport management and inventory levels. An inefficient supply chain design can lead to increased costs and decreased competitiveness [9]. [3] suggests that companies can make better decisions by utilizing optimization techniques as a basic network design and modeling tools.

Over the years, researchers have been dedicated to modeling optimized logistics networks, considering only costs between origins and customers [3]. However, with time, new variables, such as fixed costs, costs of raw material arrival, inventories stored and in transit, customer arrival time, and distance traveled, were introduced into logistics models [9].

Inventory management has also become an essential factor in logistics network modeling. Models, such as that proposed by [10], which calculate inventory cost through stock coverage, and [3], which use safety stock and storage time in multiple distribution centers, have contributed new variables to the concept of logistics network design.

In summary, some critical factors to be considered when modeling a logistics network include transportation costs, lead times, product demand, production capacity, inventory management, risk management, and environmental sustainability [2]. Understanding the cost of transporting goods, the time it takes for products to move from one location to another, the level and pattern of product demand, the availability of production capacity, the level and type of inventory to be held, and the potential risks associated with different network designs are crucial in determining the optimal network design. Additionally, the impact of network design on the environment should be analyzed, and sustainable practices should be incorporated.

In conclusion, the design and modeling of a logistics network are complex processes that require the consideration of various critical factors. To make good decisions, organizations must consider cost-related factors, lead times, product demand, production capacity, inventory management, risk management, and environmental sustainability [10, 2].

2.2 Information technology for network design

Within the realm of logistics and supply chain management, a diverse array of technologies stands at the disposal of practitioners for the purpose of network design and optimization [12, 13]. Among these technologies, the following emerge as prominent choices:

Geographic Information Systems (GIS): These systems harness cartographic and spatial analytical techniques, serving as invaluable aids for organizations in visualizing and assessing the dispersion of goods, services, and resources across geographic domains.

Linear Programming and Mathematical Optimization: These computational tools serve as indispensable instruments for organizations in their quest to discern optimal solutions to intricate logistical challenges. Optimization encompasses factors of paramount concern, including cost, time, and resource allocation.

Simulation Software: Employed for modeling and experimentation, simulation software empowers organizations to examine a plethora of scenarios within their logistics networks. This capability facilitates the identification of potential bottlenecks, the streamlining of material flows, and the minimization of operational expenditures.

Big Data Analytics: In the era of information abundance, these analytical tools equip organizations with the means to amass, process, and dissect vast troves of data from diverse sources. The outcome is a capacity for more enlightened and data-driven decision-making concerning the orchestration of logistics networks.

Artificial Intelligence and Machine Learning: These cutting-edge technologies bestow upon organizations the ability to automate decision-making processes, engendering efficiency gains by curbing the temporal and resource outlays associated with the quest for optimal solutions.

Blockchain: Emerging as a secure and transparent ledger technology, blockchain finds utility in the meticulous tracking and record-keeping of commodities, simplifying the management of labyrinthine supply chains.

It is imperative to underscore that the selection of a particular technology hinges significantly upon the distinctive exigencies and aspirations of each organization.

Table 1 furnishes a systematic classification of pivotal factors germane to the domain of logistics and supply chain management. These factors are methodically categorized as follows:

Product Characteristics: Encompassing attributes intrinsic to the products handled, this category includes parameters like product density, variety, price, life cycle, and substitutability, among others.

Service Requirements: Pertaining to the customer service and delivery facets, this category includes parameters such as cycle time, delivery frequency, order visibility, and return policies.

Demand Characteristics: Focusing on aspects of demand, this category encapsulates parameters such as demand level, volatility, density, and seasonality.

Chain Characteristics: Embracing facets intrinsic to the logistics and supply chain network itself, this category encompasses parameters such as production capacity, distance between nodes, and the number of suppliers.

Economic Variables: Responsive to economic conditions, this category includes parameters such as legal restrictions, modal transport availability, fees and taxes, and interest rates.

Environmental Variables: Pertaining to environmental impact, this category encapsulates parameters such as emissions of particulate matter and CO_2.

Table 1

Grouping of critical factors

Group	Critical Factor	
Product characteristics	· Product density · Cubic weight-volume ratio · Product life cycle · Competition level · ABC product characteristics · Product type	· Product variety · Product price · Substitutability · Product margin · Product validity · Product handling characteristics
Service requirements	· Cycle time · Delivery frequency · Average shipping weight · Average shipping volume · Item fill rate	· Customer experience · Order visibility · Return · Refueling time · Vehicle capacity
Demand characteristics	· Demand level · Demand volatility · Demand density	· Customer density · Number of customers · Seasonality

Chain characteristics	· Production capacity · Distance between nodes · Production lot size · Raw material limitations · Economy of scale	· Production flexibility · Production lead time · Number of suppliers · Location of suppliers
Economic variables	· Legal restrictions · Fees and taxes · Existing infrastructure	· Modal transport availability . Interest rate
Environmental variables	· Emission of particulate matter · CO_2 emission	

Source: Author "adapted from" [6].

Table 1 not only offers a structured elucidation of these critical factors but also references the source for further academic inquiry and examination.

3. METHOD

A comprehensive study was undertaken to conduct an in-depth analysis of the logistics network design employed by a Brazilian company engaged in the exportation of pulp and paper to the United States. This research deployed a quantitative operational research methodology, grounded in data acquired through an extensive case study approach. The study was structured as a singular-case research endeavor, with data collection accomplished through interviews with key executives responsible for the company's operational facets and a thorough examination of pertinent databases.

The dataset encompassed a diverse range of critical variables, including the temporal demand patterns exhibited by the company throughout a year, the geographical distribution of customers, the locations of distribution centers (DCs), ports, and manufacturing facilities, as well as the exacting service level requirements stipulated by customers. Moreover, the dataset encapsulated a comprehensive cost analysis, encompassing the intricacies of transportation and storage operations connecting Brazil and the USA. To facilitate the modeling and optimization of the supply chain, the study harnessed the capabilities of the Supply Chain Guru software, a product of Coupa@ [14]. The investigation systematically explored three distinct operational scenarios:

Baseline Scenario: This scenario provided an accurate representation of the company's existing operational landscape and associated cost structures.

Optimized Baseline Scenario: Here, optimization efforts were concentrated on the projected demand for the year 2021.

Optimized Future Expansion Scenario: This scenario anticipated an upsurge in demand for the year 2022 and probed the feasibility of establishing novel distribution centers to accommodate this growth.

4. RESULTS

This section details the context of the study and the information considered. It highlights the distribution network, including the location of customers, DCs, ports, and factories, and the annual customer demand. It outlines the various scenarios analyzed in the study, including the baseline scenario, the optimized as-is scenario, the Greenfield analysis, and the expansion scenario. Finally, the demand profile was analyzed to define the best inventory strategies.

4.1. Business challenge

The pulp and paper company encountered a challenge in mid-2021 when the importing rates of its products exported to the United States increased, leading to a sudden decrease in demand. Despite this, the company predicts a significant increase in demand post-2021 due to its business model review. The company seeks to optimize its distribution network, as it operated below capacity in Brazil in 2021. It is aware of potential cost-saving opportunities in its export network and increased demand from American customers.

4.2. Location of clients and facilities

In the present study, customers were grouped by location in cities. This was done as transportation costs between a distribution center and its customers remained relatively high within the same geographic region. Fig. 1 displays the locations of customers, distribution centers, and potential ports of entry in the United States. The company has three distribution centers in Baltimore, Long Beach, and Jacksonville, and 18 ports can supply these centers. The customers are represented as circles with different sizes based on their annual demand. The largest concentrations of customers are in the northeastern and southeastern regions, while the western region has few customers and markets. The primary customer is located in New York, with a demand of 4,439 tons/year. Figure 2 displays the location of the factories and ports in Brazil and shows the demand from customers who collect the products at the port of Santos, meaning the exporting company is not responsible for transportation to the United States.

4.3. Main customer demand

Fig. 1 displays a comprehensive view of the company's primary customers, their anticipated demands for the year 2021, and the proportion of each customer's demand in relation to the total market.

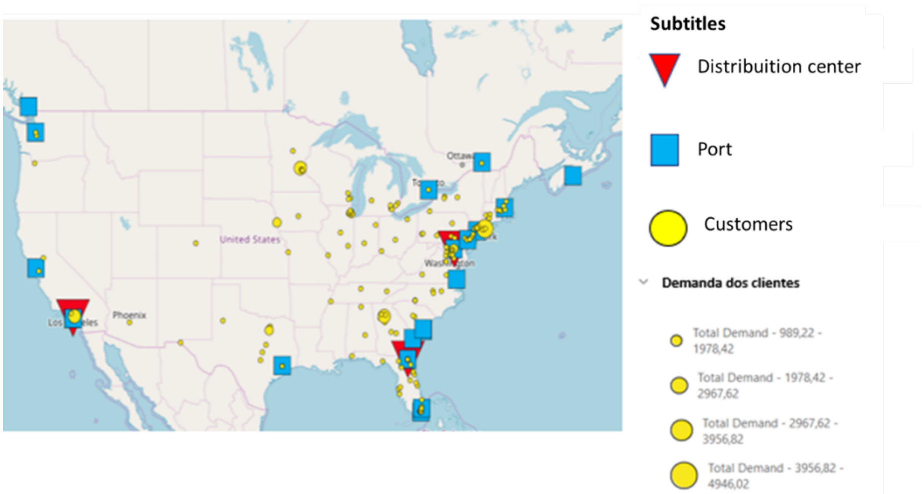

Fig. 1. Locations of customers, distribution centers, and ports in the USA

Additionally, Fig. 2 provides a geographical representation depicting the spatial relationship between factories, ports, and customers within Brazil. Fig. 3 illustrates that the highest order volume is concentrated in Santos, where customers retrieve their products from the port of Santos, representing a significant 12.7% of the entire market. Figure 1 illustrates the second-highest demand is observed in Central Islip, comprising 11.4% of the overall order volume. Norcross, Champlin, Long Beach, and Miami collectively contribute to a demand share of approximately 5%. In contrast, Baltimore, Omaha, Dallas, Fremont, City of Industry, and Philadelphia account for less than 4% of the total demand share.

4.4. Transportation costs

Table 2 shows the average transportation costs per ton between factories and ports in Brazil and Brazilian and American ports. According to the table, the cost of transportation between the Suzano factory and the Santos port by road is the lowest within the company, at U$12.10 per ton. The cost of sea freight is higher and can reach U$84.00 per ton, as seen in the charge between the Santos port and the Montreal port. Within the United States, transportation is performed by truck, and the cost between ports, distribution centers, and customers was estimated at U$3.4 per mile or U$0.136 per ton-mile. Following the company's executives, the value of U$3.4 per mile was adopted as the most reliable information for this study.

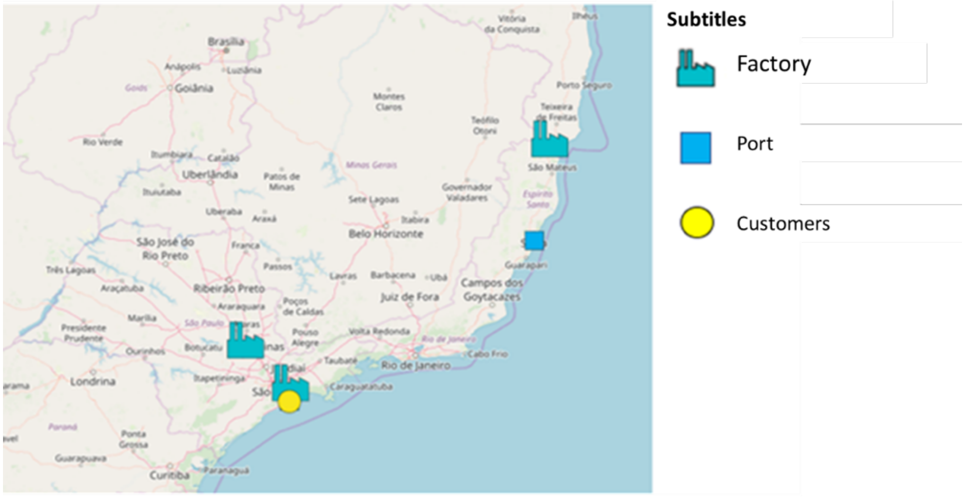

Fig. 2. Locations of factories, ports, and customers in Brazil

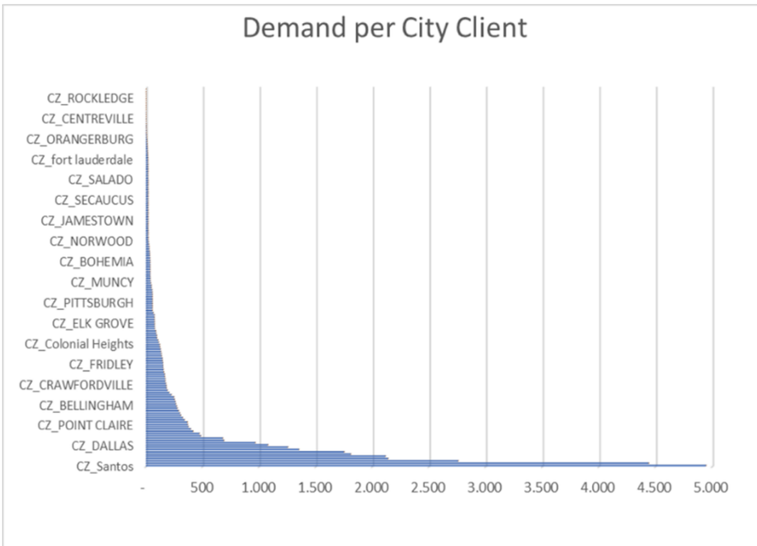

Fig. 3. Demand from main customers

4.5. Storage costs

It is essential to note that storage costs are solely variable. The company does not incur fixed operating costs, as all distribution centers are leased from external entities. Despite potential variations between the three existing distribution centers, the costs are relatively uniform. In the present study, an average cost of U$18.68 per handled ton has been adopted; this includes scenarios in which new distribution centers may need to be established.

4.6. Baseline scenario

The purpose of a baseline scenario is to replicate a company's current operation and identify inefficiencies at various stages of the network. The operating costs of the model are based on historical data for a one-year period, which considers possible variations over months. The costs of transportation, storage, and shipping operations typically make up between 10% and 15% of the company's net revenue, depending on the characteristics of the market, product, and logistics network. The baseline scenario for this company considers the demand from the year 2021. The baseline scenario is depicted in Fig.4, which shows the flow of goods from factories in Limeira and Suzano to the port of Santos and from the factory in Mucuri to the seaport of Vitória. The final transportation stage is from the port or distribution center to the final consumer.

Table 2
Average transportation costs per ton

Source	Dest	Cost
MFG_Limeira	Port_Santos	$ 25,32
MFG_Suzano	Port_Santos	$ 12,10
MFG_Mucuri	Port_Vitoria	$ 18,32
Port_Santos	Port_Baltimore	$ 58,00
Port_Santos	Port_Everglades	$ 30,00
Port_Santos	Port_Houston	$ 38,00
Port_Santos	Port_jacksonville	$ 40,00
Port_Santos	Port_LongBeach	$ 64,00
Port_Santos	PORT_MONTREAL	$ 84,00
Port_Santos	Port_New York	$ 60,00
Port_Santos	PORT_Philadelphia	$ 64,00
Port_Santos	Port_Seattle	$ 70,00
Port_Santos	Port_Toronto	$ 80,00
Port_Vitoria	Port_Santos	$ 10,00

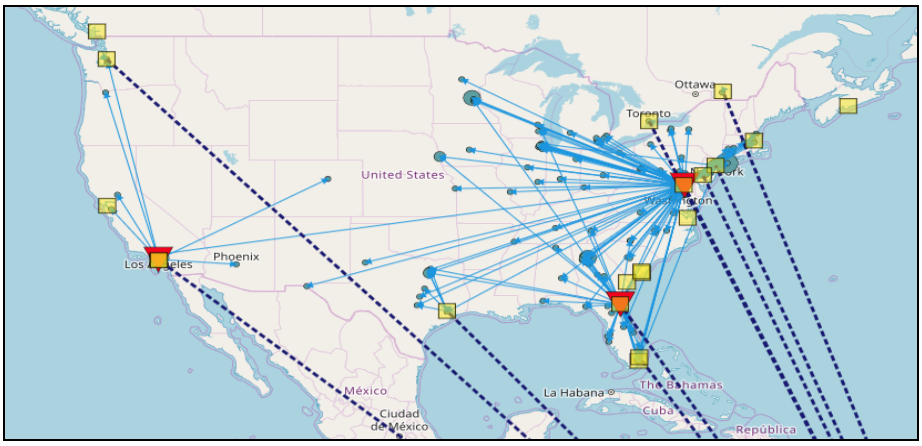

Fig. 4. Flows between ports, distribution centers, and customers in the baseline scenario

The validity of the baseline model is demonstrated in Table 3, which compares actual results with the baseline model. The results show a difference of only 0.8%, validating the baseline model as a reliable tool for forecasting the company's distribution network behavior.

4.7. Optimal as-is scenario

The optimal 'as-is' scenario represents an optimization of the company's supply chain, taking into account the demand in 2021 and the current operational structure, as depicted in Figure 5. This optimization results in a shift in the flow of goods between factories, ports, distribution centers, and customers. Notably, some ports, like Toronto, now serve customers directly. This shift leads to a reduction in the costs associated with sea freight and transportation between ports and customers, consequently lowering the total inventory costs in U.S. ports and distribution centers, as detailed in Table 4. The results of this scenario reveal an actual contribution margin of 47.1% of gross revenue, with the total demand and revenue remaining on par with the Baseline scenario. Consequently, the optimal 'as-is' scenario offers the advantage of reduced logistics costs, positively impacting the company's overall financial performance.

Table 3

Actual validity versus the baseline model

	Real	Baseline	Difference
Demand	38.945 TONS	38.945 TONS	
Gross revenue	100.0%	100.1%	0.1%
Variable production cost	35.4%	35.4%	0.0%
Packaging	1.4%	1.4%	0.0%
Shipping and documentation expenses	1.6%	1.5%	-0.1%
Factory-port freight	1.4%	1.4%	0.0%
International freight	5.3%	5.2%	-0.1%
Inland freight	4.7%	4.4%	-0.3%
Expenses at the terminal abroad	1.1%	1.1%	0.0%
Storage cost	1.0%	1.0%	0.0%
Total inv holding cost	2.7%	2.5%	-0.2%
Total cost	54.7%	53.9%	-0.8%

4.8. Expansion scenario

The expansion scenario considers a substantial increase in the company's demand for the year 2022, estimated to be nearly 148 thousand tons, representing a fourfold increase from the 2021 demand used in the Baseline and Optimal as-is scenarios. This market growth is attributed to a new focus on exports to the USA due to the company's shift in strategy. In light of this growth, the possibility of opening new distribution centers has been considered to support the expected demand growth in the coming years.

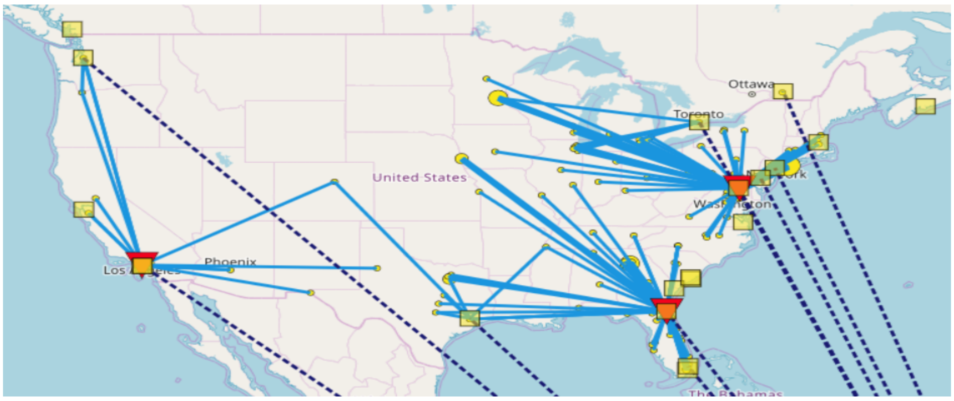

Fig. 5. The flow of goods between factories, ports, distribution centers, and customers in the USA

4.8.1. *Greenfield study and definition of optimal locations*

In the expansion scenario, the Greenfield study aims to identify the central network centroids, weighted centers of mass that consider each customer's demand. The Greenfield construction stage encompasses multiple rounds of centroid analysis to determine the locations with real service potential, given various business constraints such as the presence of immovable plants, rigid supply flows, and a comprehensive understanding of both the market and the geography of regions. The optimal locations for the expansion must balance sufficient volume and transport routes to make operations economically feasible while aligning with the company's overarching business strategy. The Greenfield analysis ultimately identified five optimal distribution center locations in California, Texas, Minnesota, New York, and Georgia, as depicted in Fig. 6. These centers will serve customers in their respective regions.

4.8.2. *Expansion scenario*

The project employs advanced algorithms to optimize the network, flows, costs, inventories, production, and transport. The network design evaluates various scenarios to determine the most cost-efficient solution for the company to respond to changes in its network, whether planned or unplanned. In this case, the best design is determined by the optimization of costs, additional investments in infrastructure, and service level. The flow between factories and ports remained unchanged from previous scenarios. In the United States of America, the flow between ports, distribution centers, and customers changed, including the need for two additional distribution centers in Minnesota and Texas, as shown in Fig. 7. These new distribution centers would receive products from ports, store them, and send them to final customers. Some ports would continue to send goods directly to customers without the need for storage at distribution centers. Table 4 presents the operating results of the expansion scenario. The expected total demand for 2022 is 148,325 tons, leading to gross revenue and a contribution margin of 48.5%. The company's highest cost remains production, with high international and domestic freight costs. With the increase in demand, the company's total operating contribution margin in the expansion scenario reached 48.5% for 2022.

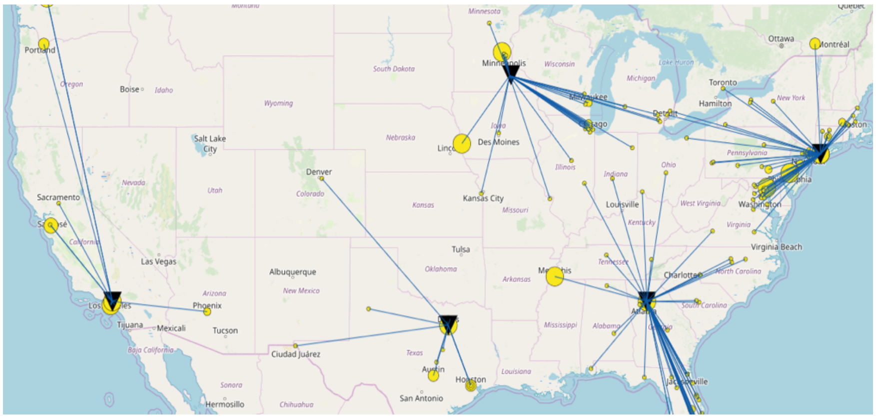

Fig. 6. Greenfield analysis for five distribution centers

4.9. Comparison among scenarios

The financial evaluation of different scenarios enables organizations to determine the benefits and returns of proposed changes. This assessment includes the organization's economic gains and qualitative factors, such as enhanced service levels, improved performance, and the acquisition of new units in the network, which may not necessarily result in financial returns. Nonetheless, these qualitative factors can play a crucial role in driving changes within the organization. The results of all optimization scenarios generated in this study are presented in Table 5.

The comparison of costs between the baseline and optimal as-is scenarios, as presented in Fig. 8, indicates that the proposed optimization scenario only had marginal impacts on the overall cost structure. As seen in Table 6, the total contribution margin in the optimal as-is scenario was 47.1%, compared to 46.2% in the baseline scenario. The slight difference between these results suggests that the current supply chain configuration is already well-optimized and efficient in meeting the demand for the year 2021. Fig. 9 presents a comparative analysis of the financial performance of the optimal as-is scenario with the baseline scenario. The results indicate that the optimal as-is scenario achieved a marginal improvement over the baseline, with a total contribution margin of 47.1% compared to 46.2% for the baseline. The total cost of the two scenarios was relatively close, suggesting that the company's current supply chain configuration and efficiency can meet the demand for 2021.

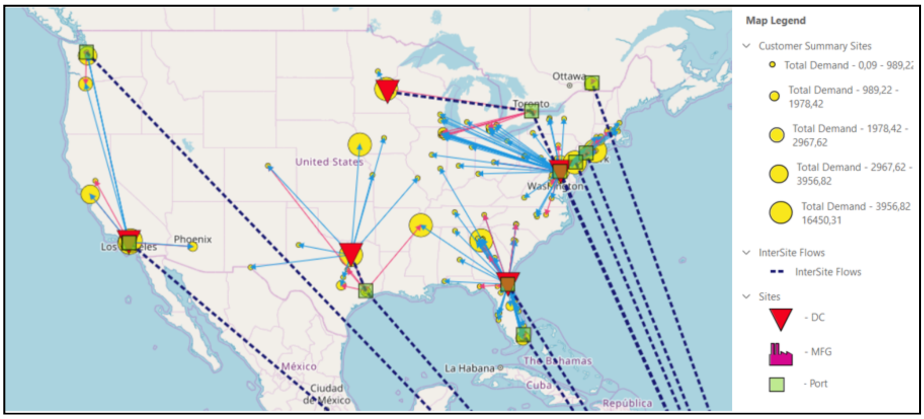

Fig. 7. Flows between ports, distribution centers, and expansion customers

Table 4

Operating results of the expansion scenario

Demand	148.325 TONS
Gross revenue	100.0%
Variable production cost	34.4%
Packaging	1.4%
Shipping and documentation expenses	1.5%
Factory-port freight	1.4%
International freight	5.3%
Inland freight	3.4%
Expenses at the terminal abroad	1.2%
Storage cost	0.9%
Inventory cost	2.0%
Total cost	51.5%

The Expansion scenario, which considers a significant increase in demand for 2022, demonstrates a substantial improvement over the Baseline scenario. The total contribution margin for the expansion scenario reaches 75 million dollars, nearly four times greater than the contribution margin of the baseline scenario. The increase in demand results in revenue and operating costs, resulting in a contribution margin of 48.5%, similar to the baseline scenario. The redesign of the logistics network and implementation of new supply and distribution strategies have resulted in a reduction of up to 2.3% in the costs of finished product circulation, storage, and distribution to the final customer while maintaining the service level. The primary improvement identified was the reduction in the cost of inland transportation in the United States, achieved by adding two distribution centers in the company's supply chain. Fig. 8 compares the main prices of the expansion scenario without an increase in the number of distribution centers and the expansion scenario with an increase in the number of distribution centers.

The results in Fig. 8 reveal that in a scenario with a demand of 148 thousand tons, the company realizes a significant increase in its financial performance with the addition of two DCs. This leads to an increase of over 125 thousand dollars compared to a scenario without the rise of two DCs. The inland freight cost, which encompasses land transportation within the United States, experiences a decrease, as does the total cost of inventory maintenance. These findings suggest that expanding the number of DCs in the supply chain network can reduce transportation costs and inventory costs, ultimately improving the financial performance of the company.

4.10. Demand and Inventory Analysis

The effective management and development of inventory policies and strategies become increasingly complex as companies expand globally, increase the number of business partners and facilities, and face rising demand for quick order fulfillment. This results in longer delivery times and more significant demand fluctuations, requiring a comprehensive analysis of inventory decisions across the supply chain. Classifying the company's product demand into made-to-stock (MTS) or made-to-order (MTO) items is necessary to minimize working capital costs and costs associated with the service level. The degree of intermittency and squared coefficient of variation of a one-year demand period can be used to classify products as smooth, erratic, slow-low variable, slow-high variable, lumpy, extremely slow, or extremely small. Products classified as smooth, erratic, and slow-low variable, with stable demand and high inventory turnover, are recommended to be kept in stock as MTS. Table 6 reveals that most of the company's products should be treated as MTS, accounting for nearly 60% of the current demand, with Smooth products alone representing 46.5% of all markets.

Table 5

Comparison of operating results for scenarios

Scenario	Baseline	Optimal as is		Expansion as is
Demand	**38.945 TONS**	**38.945 TONS**	**Comparison with baseline**	**148.325 TONS**
Gross Revenue	100,0%	100,0%		100,0%
Variable production cost	35,4%	35,4%		34,4%
Packaging	1,4%	1,4%		1,4%
Shipping and documentation expenses	1,5%	1,5%		1,5%
Factory-port freight	1,4%	1,4%		1,4%
International freight	5,2%	5,0%	-4%	5,3%
In land freight	4,4%	4,0%	-9%	3,4%
Expenses at the terminal abroad	1,1%	1,1%	-	1,2%
Storage cost	0,9%	1,0%	5%	0,9%
Inventory cost	2,5%	2,1%	-19%	2,0%
Total cost	53,8%	52,9%	-2%	51,5%
Contribution margin in $	46,2%	47,1%	2%	48,5%

Fig. 8. Comparison of the optimal as-is scenario with the baseline scenario

On the other hand, products with high demand and high intermittence variation, classified as slow-high variable, lumpy, extremely slow, or extremely small, should be treated as MTO items. MTS items can be delivered to customers from distribution centers in an average of two days from the time of order placement. In contrast, MTO items, products with high demand and intermittence variation, which makes it difficult to predict their demand, were found to be slow-high variable, lumpy, extremely slow, and extremely small, and they represent over 40% of the company's demand.

Implementing this new inventory policy has allowed the company to project a lower inventory level at its distribution centers, reducing the average inventory from 5.6 to 3.9 months. The flow of products from ports, distribution centers, and customers is presented in Fig. 10. The blue flows in the figure represent MTS products delivered from distribution centers to customers, and the red flows represent MTO products offered directly from ports to customers without passing through distribution centers. The results of this analysis indicate that MTS products are to be kept in stock and delivered to customers within an average period of two days, while MTO products are to be produced only upon receipt of a sales order and delivered to customers within an average of 45 days.

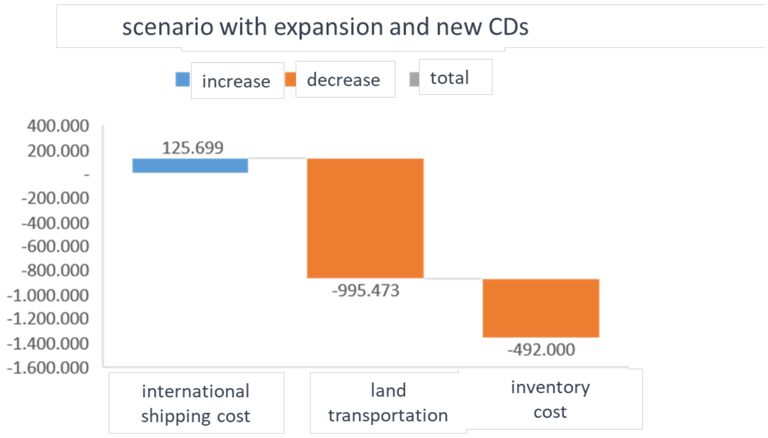

Fig. 9. Expansion scenario with new DCs versus without new DCs

Table 6

Product classification

Estratégia	Classe	Número de SKU	Demanda anual	%	Origem preferencial	Prazo Médio de Entrega
MTS	Smooth	24	17.796	46,5%	CD	2 dias
	Erratic	14	4.703	12,3%	CD	2 dias
	Slow-LowVariable	8	115	0,3%	CD	2 dias
	Subtotal	**46**	**22.614**	**59,1%**		
MTO	Lumpy	45	5.306	13,9%	Porto	45 dias
	Slow-HighlyVariable	29	4.309	11,3%	Porto	45 dias
	ExtremelySlow	231	6.027	15,8%	Porto	45 dias
	ExtremelySmall	1	4	0,0%	Porto	45 dias
	Subtotal	**306**	**15.646**	**40,9%**		
Total Geral		**352**	**38.260**			

4.11. Service level

The heat map in Fig. 11 provides a visual representation of the company's customer service time, considering the delivery time from distribution centers to customers. The blue areas indicate that customers in those regions can receive their orders within an average of one day. The green areas represent regions with an average customer service time of two days, and the red areas have an average customer service time of up to three days. This estimation was based on the average speed of 40 miles per hour for land transportation. The company can use this information to evaluate its delivery capabilities and identify areas that require improvement to increase customer satisfaction and loyalty.

4.12. Discussion of results

The data in Fig. 12 indicate a trade-off between the number of distribution centers in a supply chain and the associated costs. An increase in the number of distribution centers leads to a rise in inventory and fixed operating costs but a decrease in transportation costs up to a certain point. The optimal number of distribution centers must be determined to achieve the lowest total logistics cost. According to the current study, the ideal number was five distribution centers, resulting in the minimum cost for the supply chain.

5. CONCLUSIONS

This study investigated the optimal supply chain configuration for a pulp and paper company in light of the company's forecasted demand and the increased import taxes to the United States. The research methodology involved two stages of analysis. The first stage was the evaluation of two scenarios to determine the optimal configuration of the current supply chain using demand data from 2021. The second stage involved applying a Greenfield analysis to identify potential locations for new distribution centers. The expanded demand scenario determined the optimal supply chain configuration for a demand of 148 thousand tons in 2022. Finally, a demand analysis was conducted to determine the ideal inventory policy for each product in the company's portfolio.

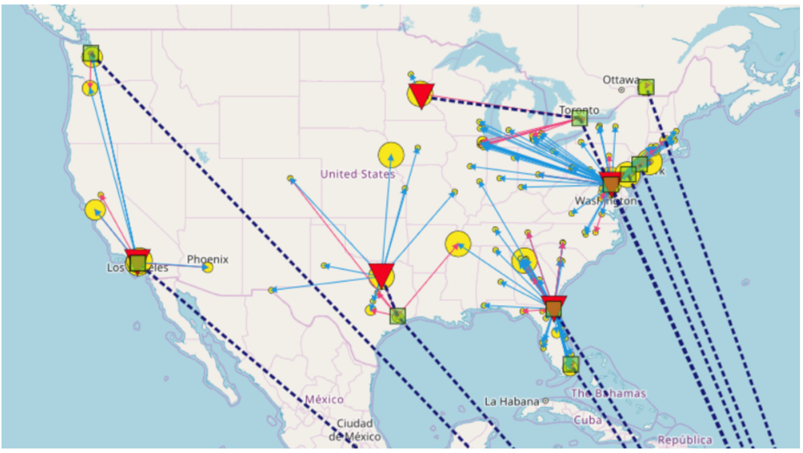

Fig. 10. Flow with the new inventory policy adopted

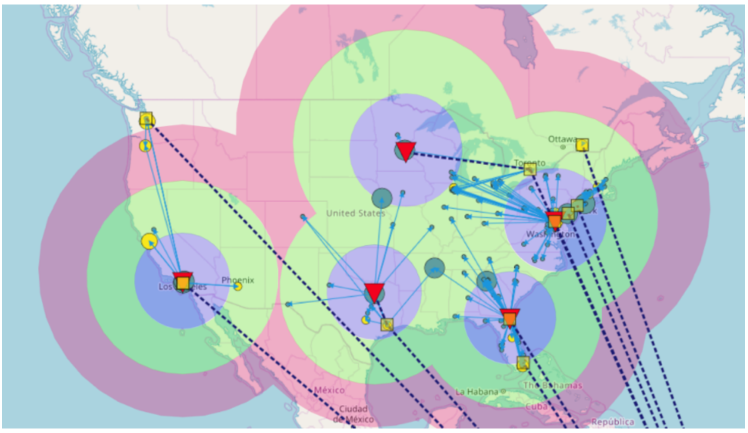
Fig. 11. Service time heat map

The results of this study indicate that while the current supply chain configuration was adequate, some improvements were necessary in terms of distribution to customers and inventory policy. Opening two new distribution centers in Texas and Minnesota was deemed essential with increased demand to reduce transportation costs and improve customer service. The study also highlighted the need to review the company's inventory policy, with MTS products stored in distribution centers and MTO products delivered directly to customers through ports.

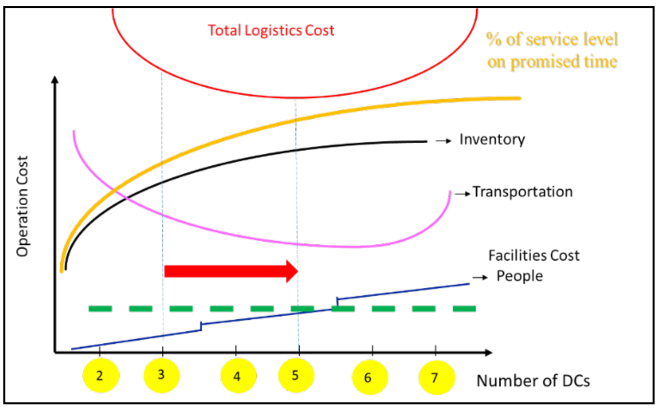

Fig. 12. Costs involved in the supply chain

The findings contribute to the existing literature on supply chain network design by emphasizing the importance of considering inventory in supply chain network design and the trade-offs between economic goals and other supply chain objectives such as cost, quality, and service level. The study provides a comprehensive and practical approach to analyzing a supply chain business process, offering valuable insights into the integration of supply chain network design. Future research should focus on monitoring the company's operations by adopting two new distribution centers or analyzing specific issues, such as high port costs in the United States and Brazil.

References

1. Govindan, K. & Fattahi, M. & Keyvanshokooh, E. Supply chain network design under uncertainty: A comprehensive review and future research directions. *European Journal of Operational Research.* 2017. Vol. 263(1). P. 108-141.
2. Jalal, A.M. & Toso, E.A.V. & Morabito, R. Integrated approach for logistics network planning: A systematic literature review. *International Journal of Production Research.* 2022. Vol. 60(18). P. 5697-5725.
3. Croxton, K.L. & Zinn, W. Inventory considerations in network design. *Journal of Business Logistics*. 2005. Vol. 26(1). P. 149-168.
4. Zokaee, S. & Jabbarzadeh, A. & Fahimnia, B. & Sadjadi, S.J. Robust supply chain network design: An optimization model with real-world application. *Annals of Operations Research*. 2017. Vol. 257(1-2). P. 15-44.
5. Chopra, S. & Meindl, P. *Supply chain management: Strategy, planning & operation*. 2007. Pearson Education.
6. Mangiaracina, R. & Song, G. & Perego, A. Distribution network design: A literature review and a research agenda. *International Journal of Physical Distribution & Logistics Management*. 2015. Vol. 45(5). P. 506-531.
7. Varian, H.R. The nonparametric approach to demand analysis. *Econometric*. 1982. Vol. 50(3). P. 945-973.
8. Ballou, R.H. *Business logistics/supply chain management: Planning, organizing, and controlling the supply chain*. 2007. Pearson Education India.
9. Daskin, M.S. *Network and discrete location: Models, algorithms, and applications*. 2011. John Wiley & Sons.
10. Abo-Hamad, W. & Arisha, A. Simulation-optimization methods in supply chain applications: A review. *Irish Journal of Management*. 2011. Vol 30(2). P. 23-46.
11. Zhang, D. & He, R. & Li, S. & Wang, Z. A multimodal logistics service network design with time windows and environmental concerns. *PLOS ONE*. 2017. Vol 12(9). No. e0185001.
12. Jimenez-Jimenez, D. & Martínez-Costa, M. & Sánchez Rodríguez, C. The mediating role of supply chain collaboration on the relationship between information technology and innovation. *Journal of Knowledge Management.* 2019. Vol 23(3). P. 548-567.
13. Litke, A. & Anagnostopoulos, D. & Varvarigou, T. Blockchains for supply chain management: architectural elements and challenges towards a global scale deployment. *Logistics*. 2019. Vol. 3(1). No. 5. 17 p.
14. Coupa, Supply Chain Guru X. Available at: https://www.coupa.com/.

Received 29.06.2022; accepted in revised form 01.12.2023