Synchronization of Ocean Export Supply Chain

by

Michelle Stephanie Ramírez Moreno
Bachelor of Production Engineering, Universidad Metropolitana

and

Yulu Li
Bachelor of Engineering (Industrial and Systems Engineering), National University of Singapore

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Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

Certified by:____
Dr. Ilya Jackson
Postdoctoral Associate, MIT Center for Transportation & Logistics
Capstone Advisor

Certified by:____
Dr. Maria Jesús Saénz
Executive Director, MIT SCM Masters Programs
Capstone Co-Advisor

Accepted by:____
Prof. Yossi Sheffi
Director, Center for Transportation and Logistics
Elisha Gray II Professor of Engineering Systems
Professor, Civil and Environmental Engineering

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Michelle Stephanie Ramírez Moreno

and

Yulu Li

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ABSTRACT

Ocean freight represents more than 70% of the global trade by volume. Given the price increases in transportation rates, companies are more interested in driving efficiencies and cost optimizations through supply chain synchronization. In this document, synchronization refers to the optimal coordination of transportation costs, inventory, and service level, while considering flexibility and sustainability. This project aims to provide an understanding of key components of synchronization, and ultimately provide a framework that illustrates the collection of supply chain elements to drive synchronization that companies can use to improve their supply chains. In order to do this, we analyzed information about the CPG company using Power BI. We performed a Center of Gravity analysis to propose the best location for the mixing center. We built a Mixed Integer Linear Programming model that provided the optimal volume allocation from the supply warehouses to the mixing center, from the mixing center to the ports of loading, and from the ports of loading to the ports of discharge. The results show that there is an opportunity to reduce 9% of the costs by optimizing the volume allocation and incorporating rail transportation in the inland freight from the supply warehouse to the mixing center and from the mixing center to the ports of loading. This project aims to represent an enabler for companies to run scenarios and decision-making.

Capstone Advisor: Dr. Ilya Jackson
Title: Postdoctoral Associate, MIT Center for Transportation & Logistics

Capstone Co-Advisor: Dr. Maria Jesús Sáenz
Title: Executive Director, MIT SCM Masters Programs

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1 Introduction

The capstone company is a multinational consumer packaged goods (CPG) company that operates in over 12 global CPG categories. The global scale gives the company a competitive strategy in knowledge sharing, efficiency improvement, and best-practice reapplication. However, it also poses the challenge of efficiently providing the optimal ocean export supply chain from different points of view as costs, time, and service level that we will discuss further in this project.

Giannakis and Croom (2004) refers to synchronization as the management of the flow of goods, while Kahn et All (2000) states that synchronization requires the coordination of different components of the supply chain, which represents a major problem for companies. Although synchronization is typically related to time coordination between different activities, after conversations with the CPG company, we refer to synchronization as the optimal coordination of transportation costs, inventory, and service level, while considering flexibility and sustainability. Therefore, in this project, we also mention costs, service level, sustainability, and flexibility as variables affecting synchronization.

Sustainability refers to the integration of environmental, social, and economic factors to create thriving, healthy, diverse, and resilient communities for this generation and generations to come (University of California, 2022). At the same time, flexibility refers to a strategy to reduce or control uncertainty and increase robustness in complex systems (McConnell, 2010). For this specific project, we will focus on the synchronization of ocean export from North America to customers in Latin America in terms of time, cost, and service.

As efficiency and decision-making are key for many companies during these disruptive times, the objective of this study is to provide a framework for companies to design a synchronized supply chain for ocean export that helps the company to run scenarios and make decisions.

This study aims to develop a practical and flexible model for continuous parameters update in the future, and learnings from this project will be reapplied to the company's exports from North America to Asia.

1.1 Background

1.1.1 Ocean export industry

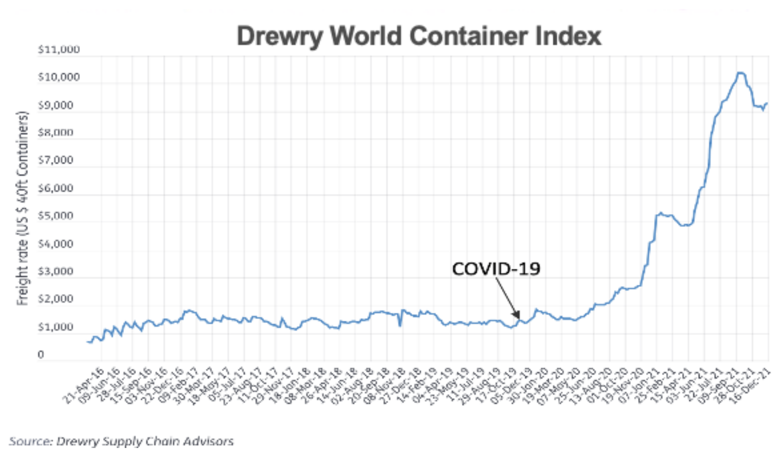
Maritime transport is critical for international trade and the global economy, representing the transport mode for 80% of global trade by volume and over 70% of global trade by value (United Nations Conference on Trade and Development, 2018).

The economic activity in the ocean is expanding rapidly, mainly behind the economic growth, trade, rising income levels, technology, and developments in the global population. However, this development has also generated climate and environmental consequences (Organization for Economic Co-operation and Development, 2022).

Beginning in early 2020, the COVID-19 pandemic disrupted supply chains, leading to canceled sailing, port delays, and container shortages. Additionally to the port situation, the pandemic generated changes in demand that led to increased volatility, contributing to significant delays (Organization for Economic Co-operation and Development, 2022).

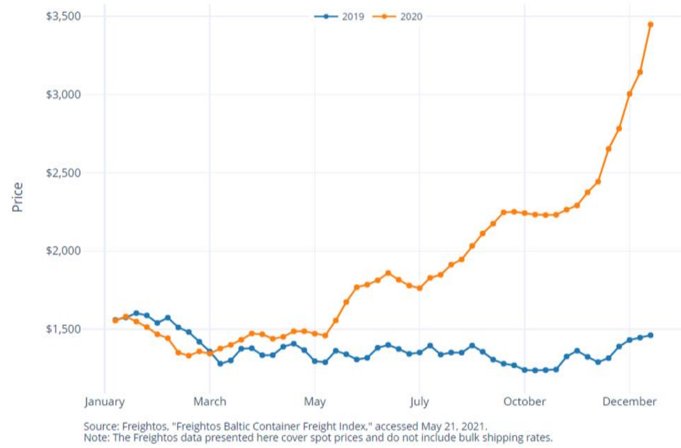
The trade contraction led container shipping firms to cancel scheduled sailings and consolidate shipping routes to focus service on major ports. As trade recovered in the second half of 2020, the container firms struggled to restore capacity to previous levels. The distribution system was shocked by the unexpected recovery in demand and firms had trouble getting products to customers. The maritime freight transportation with a recovery in demand caused vessels to operate close to maximum capacity, and as a result, there was a depletion of shipping container inventory at major ports (United States International Trade Commission, 2021). This imbalance between the demand and supply resulted in maritime freight costs as shown in Figures 1 and 2.

Figure 1 Drewry World Container Index Trend from 2016 to 2021



Note. This figure demonstrates the price increase in ocean freight from 2016 to 2021. It is noticeable that prices began to rise when the pandemic started in 2020. This increase is part of the CPG company's motivation to drive synchronization in the export supply chain. Information from the Drewry Supply Chain Advisors (2021).

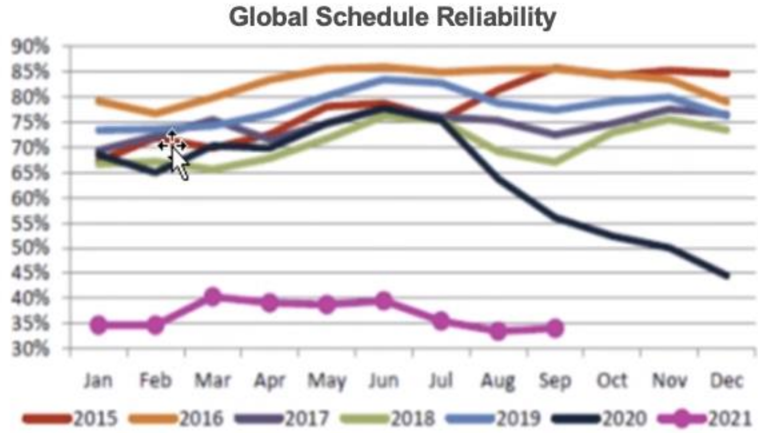
Figure 2 Weekly Index Price to Ship a Container by Vessel in 2019-2020



Note. Index price to ship a container during 2019 and 2020. This figure shows the difference in the price of the container rates between 2019 and 2020. The trade recovery resulted in the imbalance of container supply and demand, mainly in the second half of 2020. From United States International Trade Commission (2021).

As previously mentioned, the ocean export supply chain has been under tremendous pressure during the last few years. As a result, the global schedule reliability dropped from 75% in 2020 to 35% in 2021 (Figure 3), and ocean freight rates increased by 800% as compared to pre-pandemic (Figure 1) based on the information shared by the CPG company and data from Drewry Supply Chain Advisors (2021).

Figure 3 Global Schedule Reliability



Note. This figure provides a perspective of the schedule reliability from 2015 to 2021. Information from the CPG company illustrates how the planning performance and synchronization of the company have been affected as a consequence of the pandemic.

Based on the Organization for Economic Co-operation and Development report (2021), there are key considerations to manage the long-term of emerging ocean industries to contribute to growth and employment in a responsible and sustainable way. International cooperation is important to stimulate innovation and strengthen the sustainable development of the ocean economy.

It is important to strengthen integrated ocean management, which means the greater use of economic analysis and economic tools to promote innovation in processes and stakeholder engagement to be more effective and efficient (Organization for Economic Co-operation and Development, 2016). It is exactly at this point of efficiency and effectiveness that this project aims to contribute with an analysis to provide a framework that companies can implement to find the optimal solution for the ocean export supply chain and ultimately, make the best decisions for the business.

1.1.2 Defining synchronization

Capgemini Consulting (2009) defines supply chain synchronization as the ability to coordinate, organize and manage end-to-end supply chain flows – including products, services, information, and financials – in such a way that the supply chain functions as a single entity. In other words, synchronization enhances the performance of overall supply chain activities rather than siloed activities by individual functions.

Improved synchronization is critical to offset increasing costs, optimize inventory, improve lead time, and contribute to a sustainable supply chain. While there are papers that discuss organizational structures and advanced software that improve synchronization through visibility and collaboration (Capgemini Consulting, 2009), this project seeks to provide a unique perspective on synchronizing local business and export business, while developing an adaptable model that helps companies to design a synchronized ocean export supply chain considering variables as costs, times and service level.

Based on our research and our conversations with the company, in this study, we will use synchronization as the ability to coordinate costs, inventory, and service level, while considering flexibility and sustainability.

1.2 The Company and Motivation

The capstone company has 12 categories of export products manufactured by 13 plants in North America. These finished products are sent in domestic pallets to a mixing center at Greensboro, NC, for consolidation. The Greensboro mixing center performs three main activities:

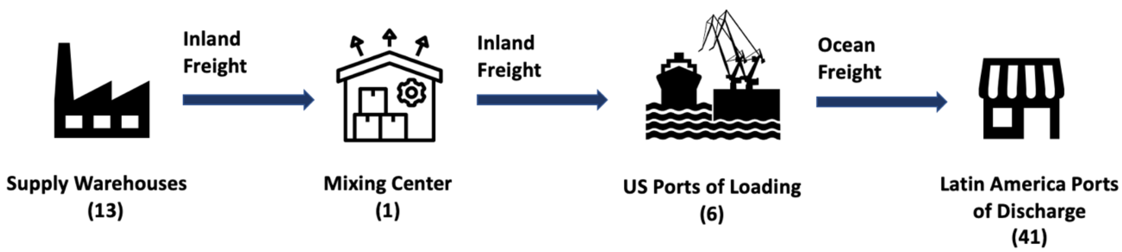
loading and unloading of trailers, case picking, and pallet exchange from domestic pallets to export pallets. The mixing center manages approximately 7,000 export containers per year and sends them to 164 customers in 37 Latin American countries via 7 carriers. This is a highly complex supply chain with significant volume and multiple touchpoints (Figure 4). However, the North American supply chain is designed and optimized for domestic shipments, not for export shipments. There are opportunities to optimize the end-to-end process for these export shipments to offset the rising global commodity costs, considering the company's existing domestic supply chain.

Figure 4 Flow from the U.S. ports to Latin American customers

Note. This figure illustrates the current flow of export products from the U.S. to Latin American customers. Information from the CPG company.

Figure 5 illustrates the supply chain design that will be optimized from the supply warehouses to the ports of discharge of the customers located in Latin America. The location of the mixing center of the CPG has a key relevance for the company given that this will determine the inland costs between the supply warehouse and the mixing center and the freight transportation from the mixing center to the corresponding port of loading. The mixing center currently receives different product categories in the Greensboro mixing center.

Figure 5 Current Supply Chain Network



Note. The perspective of a highly-complex multi-echelon and multi-product supply chain of the CPG company. Adapted from information shared by the CPG company.

There are 13 supply warehouses, and they are located in the center and East Coast of the United States, as shown in Figure 6. In this project, we will confirm if the current mixing center location is optimal or will propose a new location based on the optimization model. There are six (6) ports of loading on the east coast of the country and 41 ports of discharge located in 37 countries in Latin America.

Figure 6 Supply Warehouse and Ports Location

Note. This figure represents the geographical location of the supply warehouses and the ports of loading. Adapted from information on location of the supply warehouses provided by the CPG company

1.3 Problem Statement

There is increasing awareness of supply chain synchronization from both scholars and industry practitioners. Intuitively, synchronization is beneficial to companies; however, many find it hard to objectively evaluate the costs and benefits of synchronization, not to mention the design of a synchronized supply chain. The project postulates the following research questions: (1) What should be considered in designing a synchronized supply chain for ocean export? (2) How do companies make tradeoffs among factors affecting supply chain synchronization? In this project, we are developing an easily adaptable model for synchronized supply chain network design, through the optimal volume allocation from the ports of loading to the ports of discharge, and considering the most efficient transportation mode for the inland freight from the supply warehouses to the mixing center and from the mixing center to the ports of loading.

As synchronization is key to our project, we identified the main variables affecting supply chain synchronization - cost, time, service level, sustainability, and flexibility. Based on the dataset available from the CPG company, we conducted our research in the following steps.

1. Collect data and conduct descriptive analysis to understand the scale of the ocean freight in the CPG company. This includes the number of containers shipped; the number of ports of loading, ports of discharge, and customers; and transportation cost.
2. Build a framework for supply chain synchronization design. This framework will help companies identify and compute key performance metrics to contribute to the synchronization of their supply chain.
3. Build a use case of the framework with the CPG dataset for framework validation.
    a) Inland transportation costs: We plan to conduct a Center of Gravity analysis to propose the best location of the mixing center with minimum inland transportation costs.
    b) Ocean freight costs: We will use Mixed Integer Linear Programming to propose the optimal volume to allocate to each carrier to minimize the total ocean freight costs considering capacity restrictions, route availability, and customer demand. This method also facilitates the easy update of model parameters for business scenario simulations.
    c) Simulation analysis: We will identify the key variables that affect synchronization in the ocean export supply chain. Propose tradeoffs among synchronization factors according to the CPG company’s resources and needs.

4. Research about ocean industry best practices. To identify improvement opportunities, we will propose best practices in the ocean industry as well as other CPG companies' practices that can be reapplied to our partner CPG company and to the ports of loading used to ship the finished product to Latin America.

5. Provide managerial recommendations. Based on the analysis and the developed framework, we will incorporate insights and recommendations that support the decision-making of the company.

2 Literature Review

A literature review was conducted to identify and propose supply chain methodologies to address the problem under consideration. Main topics include the key metrics to drive synchronization, the characteristics of ocean transport, optimal location for facilities, ocean export innovation, and best practices to be recommended to the company to drive synchronization of their supply chain.

2.1 Key Variables for Synchronization

This CPG company has suffered the consequences of supply chain disruptions that have affected production, service, costs, and delivery schedules. Companies can use supply chain synchronization as a strategy to manage, recover and set the future of supply chains (Pellathy, Burnette, Stank, 2020).

Based on the research developed by Pellathy, Burnette and Stank (2020), there are three main factors that provide guidance to synchronizing supply chains as shown in Figure 7.

Figure 7 The Three P's of Supply Chain Synchronization

	END-TO-END	BUILDING RELIABILITY AND PREDICTABILITY	CULTIVATE A SUPPLY CHAIN CULTURE
PHYSICAL SUPPLY CHAIN	Are we making the right physical investments to meet the requirements of core business drivers? When do physical investments need to be made? Are upstream and downstream partners making the right physical investments? Are there physical investments already in the supply chain that can be better utilized?	How flexible are physical assets? Can they support multiple business/customer requirements? Are physical investments being maximally utilized? What is our gross profit margin? ROA on fixed assets? EVA? Are there ways to reduce the physical footprint through digitization? Outsourcing?	Are we building technical mastery and strengths into the team, while also building new skills and an appreciation of technological change? Are we ensuring that all employees have visibility into current and future challenges and giving them a chance to grow new hard and soft skills that are key to remaining competitive in a dynamic work environment?
BUSINESS PROCESSES	What is the appropriate timing for the output of business processes? Are we taking an end-to-end approach in our management of key business processes, including customer relationship management, sales forecasting and demand management, production and operations management, purchasing and supply management, order fulfillment, resource management, new product development, end of product life and commercialization, reverse supply chain management, and data management? Do supply chain stakeholders adopt a process perspective that focuses on optimizing the overall flow of supply chain activities, rather than simply executing activities at the stakeholder's individual node? Do stakeholders work to resolve conflicts in decision making to ensure that the sequencing and timing of activities are matched with maximum efficiency?	How flexible are our business processes? Can they adapt to meet changing business/customer requirements? Are business processes maximally efficient and effective? What is our NOPAT? EVA? Cash-to-Cash? Are there ways to reduce business process complexity? Are there ways to reduce working capital requirements? Are there ways to digitize and/or automate business processes? Outsourcing? Are we eliminating waste, critically evaluating redundancies, avoiding rework and returns, delivering innovation, and carefully managing variation in our business processes?	Are we investing in cultivating the adaptability, emotional intelligence (EQ), and political skills needed by successful end-to-end business processes? Are we emphasizing change management as a critical element of overall supply chain skill set? Are we providing the time and experiential learning needed to build a deep reservoir of talent in our supply chain leaders?
PEOPLE SYSTEMS	When will key positions come open? What is our development plan for incoming supply chain talent? What is our supply chain succession plan? Do we know the supply chain talent gaps of our key partners?	How do we manage replacement for retirements versus new additions for tomorrow's jobs? How do we manage employee flex time? How many resources are we devoting to hiring, training, and developing supply chain talent? Can those resources be better utilized?	How are we building norms and values that support a holistic, end-to-end systems approach to supply chain management?

Note. The three Ps of supply chain synchronization. From "End-to-End Supply Chain Synchronization: A strategy for uncertain times" by Pellathy, D., Burnette, M. and Stank, T. (2020) propose guidance regarding the synchronization of supply chains.

In order to identify key variables that can help to improve synchronization, it is important to understand what variables can be measured with the information provided. Figure 7 states the importance of providing flexibility to business processes and investing in cultivating adaptability as key aspects to contribute to the synchronization of supply chains. Based on these factors and the information that the CPG company provided, we will study and develop a framework that considers the relevance of flexibility and adaptability for different assumptions to enable the assessment of business scenarios for the decision-making of the company. Key variables for synchronization include costs, lead time, service level, sustainability, and flexibility. In the next sections, there is a description of each key variable identified.

2.2 Cost Composition

For the synchronization of the supply chain of the CPG company, we have identified different costs that are important to consider when evaluating different scenarios. This includes transportation, inventory holding, labor, warehouse, and stock-out costs.

2.2.1 Transportation Cost

The transportation costs include a combination of different charges related to port expenses, custom process, administrative fees for customs clearance and technical control, customs broker fees, terminal handling charges, and additional fees depending on specific circumstances. The ocean freight rates summarize the combination of different costs that include freight pick-up, freight transport, export charges, import charges, delivery, fuel, and risk (Yum, 2013). The ocean freight rate depends on the type of container used, and there is a high dispersion of transport across countries (Behar & Venables, 2005).

2.2.2 Inventory Carrying Cost

The Inventory Carrying Cost (ICC) refers to the cost incurred by the company to hold the inventory during a period of time. This cost includes expenses related to storing or holding the products, warehousing, labor, insurance, and rent (Lopienski, 2019).

2.3 Lead Time

The lead time refers to the amount of time between a process initiates and finishes (Lester, 2017). Failure to replenish stock is mostly caused by lead time delays, which affect the inventory and customer satisfaction. According to Sharman (2019), extended lead times can end up costing the organization money and there is a risk of running out of inventory or using unreliable suppliers. Speed to market is important for companies in a context where competitors might introduce new products quicker and take market share.

The reduction and accurate forecast of lead times represent a key element for any operation. Some of the steps recommended by Sharman to manage the supply chain and contribute to reducing the wait include:

- Use of domestic suppliers: When companies use domestic suppliers, they can reduce the lead time considering how long it takes compared to shipping from foreign countries.
- Increase order frequency: Companies usually think that placing an order of one large bulk represents savings. If this means longer lead times, the company may consider other factors. The company might discover they are losing money if they factor in potential lost sales or increased labor for inventory management. Therefore, ordering smaller quantities more frequently can contribute to the reduction in lead times and carrying costs.
- Provide sales forecasts: It is important for companies to anticipate their suppliers letting them know when to expect reorders based on actual sales data. This also speeds up the fulfillment process and they will be ready to ship when the company confirms the order.

- Suppliers consolidation: While it is common practice to have backup suppliers, it is also important to avoid the coordination of multiple vendors that prevent the company to place the orders in a timely manner affecting lead times. When possible, it is important to reduce the time spent handling multiple accounts and implement vendor management software that contributes to the streamlining of the process and creates efficiencies.
- Create incentives and communicate regularly: The company may consider offering a bonus to the supply chain vendor if they complete the orders on time or ahead of schedule. On the other hand, staying in touch with the suppliers throughout the process helps to set expectations and if necessary raise any issues that can be addressed promptly. Also, providing key performance indicators will help to motivate the suppliers to achieve the service levels the company expects.

2.4 Service Level

From a business perspective, the service level represents a tradeoff between the cost of inventory and the cost of stock-out (Schalit & Verorel, 2014). In most sectors, targeting high service levels is the norm since this is one of the key factors to strengthen customer loyalty. Caplice and Ponce (2020) refers to cycle service level as the probability that there will not be a stock out within a replenishment cycle, which is one minus the probability of a stock-out occurring. According to Hartunian (2015), service level has proven to be an objective metric that relates cost to risk, enabling the optimal allocation of scarce inventory dollars. This allows measurement and reporting compared to certain standards in order to offer responsiveness, timeliness, reliability, and uptime.

The service level represents a tradeoff between the cost of inventory and the cost of stock-out. According to Schalit and Verorel (2014), the service level can be also defined as the probability of being able to service the customers' demand ever facing backorders or lost sales. The service level is relevant where future demand is uncertain. In practice, the inventory manager needs to settle for an imperfect inventory trade-off. This trade-off is measured through the notion of service level.

Retailers or manufacturers try to satisfy as many customers as possible to maximize their sales and revenue. However, maintaining the corresponding inventory is costly and risky, given that products are expensive to buy or produce, they need space to be stored, they expire, and get obsolete. While more inventory is carried, the costs and risks are higher.

2.5 Sustainability

During the last years, the concept of sustainability has taken greater importance between different industries and companies. In this context, the strategies of the company must be aligned with environmental, social, and economic dimensions (Hristov, Chirico, 2019). It is a challenge to identify the suitable KPIs that best describe and help companies to achieve their sustainability goals.

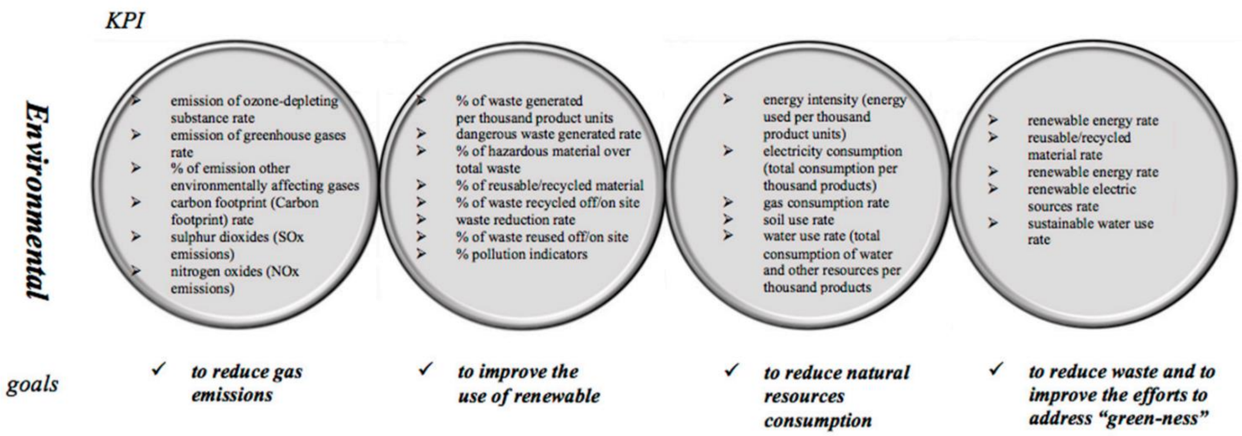
2.5.1 Environmental Performance Indicators

The environmental approach encompasses the role of natural resources, their use, the reduction of nonrenewable resources, material degradation, and natural processes. Some indicators include:

- Pollution issues
  - CO2 and gas emissions
  - The ozone layer is linked to indices on the apparent consumption of ozone-depleting substances (ODS)
  - Air quality by computing SOx and NOx emissions
  - Waste generation
  - Freshwater quality
- Natural resources and assets
  - Freshwater resources for consumption and waste
  - Climate change
  - Fish resources
  - Fish resources
  - Energy resources
  - Biodiversity

From these indicators, the most important metrics based on the analysis of the University of Rome Tor Vergata (2019) include (1) gas emissions; (2) renewable resources; (3) resource consumption; and (4) waste. Figure 8 provides a perspective of the main environmental indicators.

Figure 8 Environmental Performance Indicators



Note. The Role of Sustainability Key Performance Indicators (KPIs) in Implementing Sustainable Strategies by Hristov, I., Chirico, A. (2009) propose guidance regarding the measure of sustainability from the environmental point of view.

2.5.2 Social Performance Indicators

The social approach is related to the capacity to provide equality to citizens' for value creation. The main factors include (1) encouraging employees to accept cultural change; (2) improving the quality of work conditions; (3) guaranteeing respect for human rights; and (4) participating in social activities. Given the scope of this project in ocean freight, the optimization model will not include this dimension, which could represent the direction for future research.

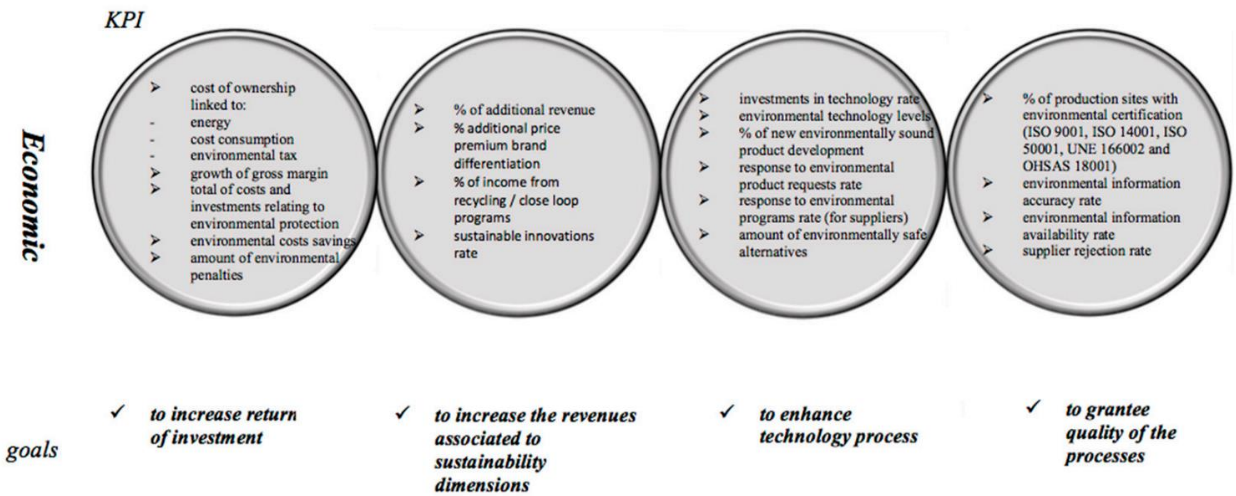
Figure 9 Social Performance Indicators

Note. The Role of Sustainability Key Performance Indicators (KPIs) in Implementing Sustainable Strategies by Hristov, I., Chirico, A. (2009) propose guidance regarding the measure of sustainability from the social point of view.

2.5.3 Economic Performance Indicators

The economic dimension refers to the capacity to create durable growth to generate revenue and employment, sustain the population, and efficiently employ resources (Hristov, Chirico, 2019). The main indicators highlighted in the study of the University of Rome Tor Vergata include (1) the growth of the gross margin ratio derived from the sustainability strategy adopted; (2) costs and investments related to environmental protection; (3) financial indicators that evaluate value creation.

Figure 10 Economic Performance Indicators



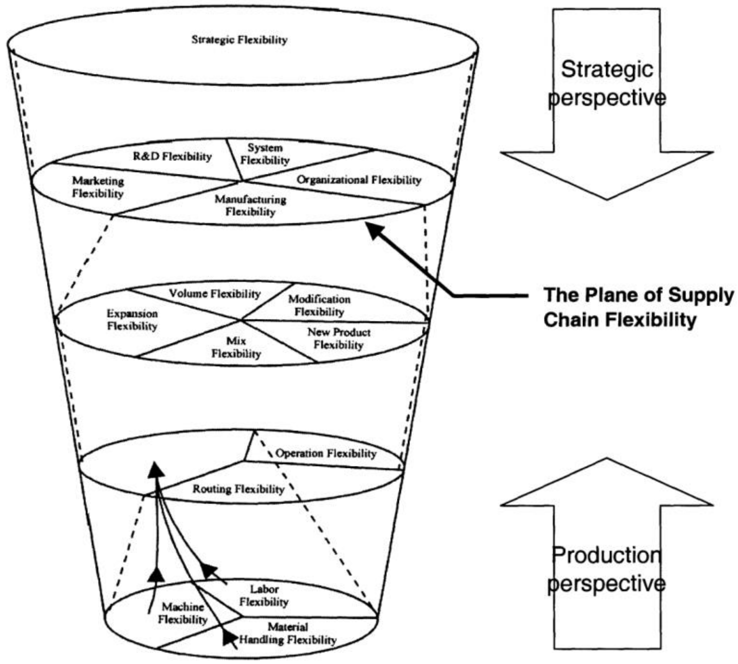
Note. The Role of Sustainability Key Performance Indicators (KPIs) in Implementing Sustainable Strategies by Hristov, I., Chirico, A. (2009) propose guidance regarding the measure of sustainability from the economic point of view.

2.6 Flexibility

As mentioned in Taylor's (2003) study, different authors define flexibility as “the ability to change or react with few penalties in time, effort, cost, or performance”. According to McConnell (2010), flexibility adds value to the system while allowing it to adapt to future circumstances that are not known. Similarly, the study of Acero, Saenz and Luzzini (2020) refers to flexibility as an ability for companies to cost-effectively vary the output of a process to create strategies that mitigate risks.

Taylor and James (2003) examined extensively types of supply chain flexibility: product flexibility, volume flexibility, mix flexibility, market flexibility, and logistics flexibility. Together, they create a time-based advantage for businesses and supply chains. In the context of this project, we are concerned about volume flexibility and logistics flexibility. More specifically, do we have multiple logistics options when one distribution route is tight?

Figure 11 Flexibility Literature Funnel



Note. This graphic shows the layers of flexibility considering the strategic perspective and the production perspective. From the study of managing flexibility in supply chain by Taylor (2003).

The flexibility funnel developed by Taylor (2003) shows the layers of flexibility that include the plane of supply chain flexibility. This plane includes manufacturing flexibility, organizational flexibility, system flexibility, R&D flexibility, and marketing flexibility. As Taylor stated, flexibility is related to the ability of companies to have a positive and significant impact on responding to changes. In this project, we are focused on allocating the volume to the optimal route and assessing the option of transporting goods through truck or rail from the supply warehouse to the mixing center and from the mixing center to the port of loading.

2.7 Characteristics of Ocean Transport

Common transportation modes used in business settings include air, ocean, trucking, rail, intermodal, and barge. Caplice and Ponce (2021) examined the feasibility of each transportation mode under different situations, such as geography, required speed, shipment size, and product restrictions.

In the 1970s, containerization revolutionized the ocean transport industry according to Fransoo and Lee (2012).

Today, nearly 80% of international trade in terms of volume is shipped by sea. In 2020 alone, 10.7 billion tons of trade were seaborne, which is equivalent to 815.6 million Twenty-foot Equivalent Units (TEUs) (United Nations Conference on Trade and Development, 2021).

2.8 Export Center Optimal Location

The location of the mixing center will be an important factor for the optimization model to develop given that facilities' locations and transportation costs can represent up to 80% of the supply chain costs of a company according to Collings and Wang (2019). For this specific project, the location of the mixing center will be critical to determine the costs from supply warehouses to the mixing center and, afterward, the cost from the mixing center to the port of loading.

To design a strategic design that guarantees the optimal location for the mixing center, it is important to consider such key factors as land availability, cost-effective access to labor, proximity to supply warehouses, proximity to the port, and access to logistics facilities. Qualitative information is considered based on observations or context analysis to identify potential candidate sites. Later on, the quantitative input is key to proposing an optimization model to design the network based on important variables such as transport costs, capacity, labor costs, demand, and customer service level, among others (Noday, 2014).

The location of the CPG's mixing center can be determined through different methods influenced by the structure and the potential network changes of the supply chain. For optimization problems, there are different methods, including mixed-integer linear programming, center of gravity method, branch & bound, and heuristics (Baghalian, Rezapour, & Farahani, 2013). Besides, other optimization methods such as the Minimum Cost Flow Problem can be used for network optimization (Orlin, 1989).

Considering the objective of the company of using this model to assess different business scenarios, it is very important to consider a method that can be easily updated, allowing the company to make decisions based on the adjustment of the model to new assumptions. There are two potential methodologies to be used for the optimization problem: the Mixed Integer Linear Programming and the Minimum Cost Flow Problem Method.

2.9 Ocean Export Innovation

Although the main focus of this project is to develop the optimization model, the company is also interested in reapplying best practices of the ocean industry in their processes.

2.9.1 Container Triangulation

In recent years, new digital technologies and data solutions have been developed to reduce inefficiencies in the transportation process. One of these solutions is container triangulation, which refers to the optimization of container transportation routing by reusing the import containers for export while matching the needs of importers and exporters. This solution represents an important opportunity for the carriers to reduce empty container transportation and improve the turnaround (Feng & Moreno, 2021).

To improve the utilization of the assets, the triangulation starts when a trucking supply picks up import-laden containers from the port to the import infrastructure for unloading. After an inspection process, the trucking supply transports the empty container to the export premise. The exporter loads the container, and the laden container goes back to the container terminal. This re-utilization of containers reduces the traveled distance of the containers and reduces container shipments, lead times, costs, and gas emissions (Feng & Moreno, 2021).

In this research, we identified that it would be feasible to apply triangulation on certain routes from the U.S. to Latin America, such as the route to the Dominican Republic since the company has export but also import operations in this country, representing an additional opportunity for financial and sustainability benefit for the company.

2.10 Best Practices

Based on the study of Burnette, Meline and Pellathy (2020) from the University of Tennessee, there are best practices of companies developing end-to-end synchronization in industries such as CPG, chemical, packaging, health care, food, and equipment.

- Multi-functional strategy leadership/ownership: This practice was the most frequently mentioned in the study of the University of Tennessee. It is important to consider the multifunctional support, ownership, and role modeling of the strategy by top leaders across every business aspect.

- Aligned core business driver: The core business driver is what makes the synchronization strategy unique. Some core business driver analysis includes the active participation of all functions providing data and knowledge to the process.
- Solid supply chain foundation (end-to-end, dependable): This strategy is related to reliability/predictability/zero waste. The system is reliable and predictable as the weakest link. The highest levels of waste are typically at the ends of the supply chain including a lack of integration, information, and synchronization with suppliers and customers.
- Skills and capabilities to enable synchronization: This practice includes influencing and boundary management, business analytics through digital tools, value stream mapping, leading agility and dependable operations, leadership skills, and multifunctional business process skills and experiences.
- Value stream mapping and flowcharting: This practice focuses on delivering the end business objective through design, source, make, deliver, sell, and service.
- Segmentation to create focus: This strategy refers to how the company can generate the most value through prioritization.
- Supply chain agility enables synchronization: This practice refers to the core business driver. The capability involves improving supply chain responsiveness and agility through time reductions, rapid changeover, and capacity improvements.
- End-to-end supply chain visibility and optimization (digital): This strategy refers to physical-digital tools and information/analytical technology. Supply chain visibility, data-based

decisions, and optimization are critical capabilities to use the information and manage the supply chain.

2.11 Conclusion

In recent years, the interest in supply chain synchronization has been increasing to offset inefficiencies and complexities in the field. However, there is a gap in studies for synchronization metrics and best practices for the adoption of synchronization. This project serves to close this existing gap with the research and incorporate key variables that affect synchronization. Based on our research we will incorporate costs, lead time, and service level as inputs for our model, but also we will build a model that can be easily updated to provide flexibility to the business. Furthermore, considering the importance of sustainability for companies, we will run scenarios that allow them to assess scenarios of volume consolidation. Optimization modeling and real-world applications will be used to help companies to run scenarios and enable decision-making.

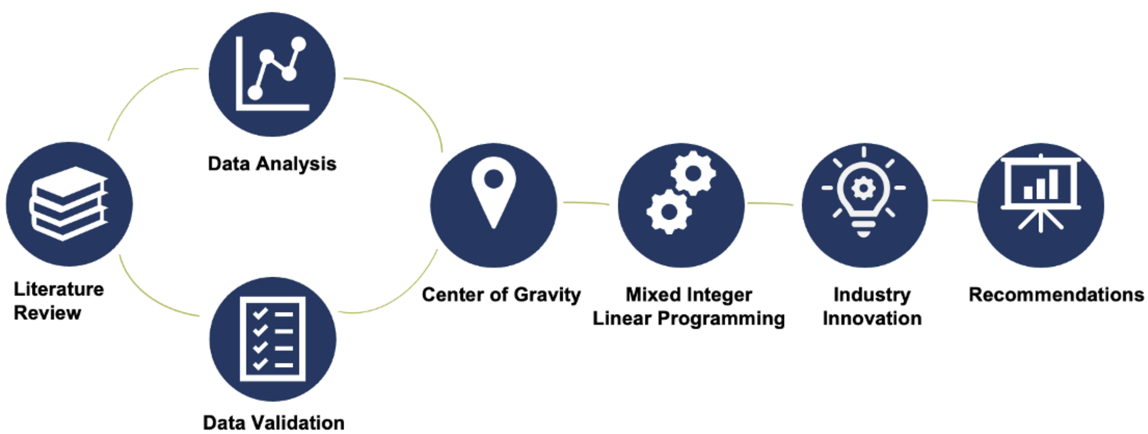
3 Methodology

The methodology starts with data analysis and validation of the dataset obtained from the CPG company. Then a center of gravity analysis is conducted on the existing supply chain to understand whether the current mixing center location makes sense. Next, we take a strategic view of the supply chain network focused on mixing center location and volume allocation strategy through a Mixed Integer Programming Model (MILP). Finally, ocean industry research is presented to share the latest innovations that the company can apply.

Figure 12 shows the methodology flow process followed in this project. It visually reflects a summary of the process and the key points developed to provide the expected model and research.

The key concepts that we have extracted from the literature review include synchronization, costs, service level, lead time, sustainability, and flexibility. We also studied best practices and the importance of providing visibility and optimization to the business. Based on the preliminary research, we incorporated these variables and concepts in our methodology and further analysis to build the framework that contributes to supply chain synchronization.

Figure 12 Methodology Flow Chart



3.1 Data analysis and validation

Before going into the details of any proposed technique to solve the problem of the company, we focused on collecting and understanding the available data. We built visualizations in Power BI to better understand the current volume flow, container distribution by port, volume by port of discharge, and the cost perspective. This data analysis helped to ask clarifying questions to the company contact and recommend the next steps according to the available information. This analysis was also helpful in identifying outliers in terms of ocean freight cost of containers from North America to different ports of discharge in Latin America.

3.2 Examine current supply chain performance

3.2.1 Center of Gravity

One of the key questions for the company is to identify the optimal location of the mixing center that is required to send the shipments of different categories to the ports of loading and ultimately to the ports of discharge in Latin America. Given the need of the company and based on the research, the proposal was to perform a center of gravity analysis that could provide a recommendation for the mixing center location and confirm if the current location is suitable for the business.

The center of gravity (COG) analysis consists of locating the facility considering the existing facilities, the distance between them, and the volume of goods to be shipped between them. This methodology involves expressions to compute the two-dimensional coordinates of the point where the distance between facilities and their expected volume of transportation activity is minimized (Schniederjans, 1999). The following formulas are used to compute the COG analysis:

Notation:

C_x: horizontal axis for the new facility location

C_y: vertical axis for the new facility location

d_{ix}: X coordinate of the existing ith location

d_{iy}: *Y* coordinate of the existing ith location

V_i: volume of goods transported from the *i*th location

$$Cx = \frac{\sum dix \cdot Vi}{\sum Vi} \quad (1)$$

$$Cy = \frac{\sum diy \cdot Vi}{\sum Vi} \quad (2)$$

The results of the mixing center's optimal location using Center of Gravity analysis can be found in chapter 4.2.1.

3.2.1.1 Sustainability

Ocean freight represents 4-5% of global carbon emissions and companies transfer ship goods through full containers under-utilizing the capacity and resulting in a higher carbon footprint per volume shipment (Laik & Way, 2019). We observed that the CPG company has an opportunity in the container fill rate of the Caribbean Islands, which currently is shipping with a container efficiency of 62%. In order to propose a consolidation that can increase the container efficiency and reduce the carbon footprint, we performed a center of gravity analysis for the location of the volume of the Caribbean Islands which can be found in chapter 4.2.1.1.

3.3 Mixed Integer Linear Programming (MILP)

The MILP identifies the optimal location scenario that guarantees the minimum cost while considering certain constraints. MILP is typically used to provide a user-friendly experience and robustness for large optimization problems where there is a need of running different scenarios (Noday, 2014).

As the synchronization is the key factor in this project, the input variables of the problem include: supply by supply warehouse (in number of containers), demand and standard deviation of demand by port of discharge (in number of containers), lead time (via truck, railroad, and ocean), cost of running the mixing center, target service level, review period by port of discharge, and container fill rate by port of discharge. Based on the research, the proposed methodology was to use Python and the Gurobi package for optimization.

According to Collins and Wang (2019), the key variables and expressions for the Mixed Integer Linear Programming mathematical formulation include:

Z: total cost to be minimized by the MILP

x_{ij}: volume (pounds) shipped from a station $j \in J$ to a customer node $i \in$ I (zip code), where *J* and *I* stand for the sets of stations and customer nodes respectively.

Continuous variable

d_i: volume (pounds) of demand for each customer node *i* (zip code), continuous variable

y_j: Indicates whether this station $j \in J$ is used or not, binary variable

c_{ij}: Transportation cost applied to arc from one station $j \in J$ to one customer node $i \in I$ (zip code), coefficient

f_j: Fixed cost to operate a station, coefficient

M: An arbitrary large number to link the volume with the facility

n: Number of facilities to be decided in the model

$$min\, Z = \sum\sum c_{ij}x_{ij} + \sum f_j y_j \quad ; \quad \forall\, i \in I\,, \quad \forall\, j \in J$$

Subject to:

$$\sum x_{ij} \geq d_i \; ; \;\; \forall \, i \in I$$

$$x_i \; - \; My_j \; \leq 0 \; ; \;\; \forall \, i \in I \, , \forall \, j \in J$$

$$x_{ij} \; \geq 0 \; ; \;\; \forall \, i \in I \, , \forall \, j \in J$$

$$y_j = \{0, 1\} \;\; ; \;\; \forall \, j \in J$$

$$\sum y_i = n \; ; \;\; \forall \, i \in I$$

In order to provide the optimal cost for the company, it is necessary to use a mathematical model that provides a recommendation considering different variables that will be explained later in this chapter 3.3. Considering the complexity of the problem and the need to integrate different variables with the ability to be easily adaptable, we proposed to build a Mixed Integer Linear Programming (MILP) model.

In this model, the objective function is to minimize costs, which include the transportation cost, the cost of running the mixing center, and the inventory holding cost. It is important to note that the transportation cost includes the transportation from the supply warehouses to the mixing center, the cost from the mixing center to the port of loading, and the ocean freight cost from the port of loading to the ports of discharge.

As this project aims to provide flexibility to the business, the proposed model includes the alternative of providing an inland freight recommendation through trucks or railroads from the supply warehouses to the mixing center, and from the mixing center to the ports of loading. This recommendation will depend on the transportation rate cost, but also it will consider the inventory holding cost based on the lead time and the expected service level.

Notation:

SW: supply warehouse

MC: mixing center

$tc_{SW,MC}$: truck cost from the supply warehouse to the mixing center

$rc_{SW,MC}$: rail cost from the supply warehouse to the mixing center

$tc_{MC,POL}$: truck cost from the mixing center to the port of loading

$rc_{MC,POL}$: rail cost from the mixing center to the port of loading

$oc_{POL,POD}$: ocean cost from port of loading to the port of discharge

opc: operational cost

$tf_{SW,MC}$: truck flow from the supply warehouse $i \in I$ to mixing center

$tf_{MC,POL}$: truck flow from the mixing center to port of loading $i \in I$

$rf_{SW,MC}$: rail flow from the supply warehouse $i \in I$ to mixing center

$rf_{MC,POL}$: rail flow from the mixing center to port of loading $i \in I$

of: ocean flow

Ce: holding cost

D_{POD}: demand at port of discharge

R_{POD}: review period at port of discharge

σ_{POD}: standard deviation of demand at port of discharge

k: corresponds to the confidence in the data points within a certain standard deviation value (k = 2.05 based on 98% service level)

L_{POD}: lead time at port of discharge

$Supply_{SW}$: supply at supply warehouse

$POD_{POL,POD}$: volume from POL to POD

Open: refers to an active site or flow between two sites (supply warehouse, mixing center, port of loading or port of discharge)

$Open_{MC}$: binary to reflect an open mixing center

$RailOpen_{SW,MC}$: binary to reflect an open rail flow from supply warehouse *i* to mixing center

$TruckOpen_{SW,MC}$: binary to reflect an open truck flow from supply warehouse *i* to mixing center

$RailOpen_{MC,POL}$: binary to reflect an open rail flow from mixing center to port of loading *i*

$TruckOpen_{MC,POL}$: binary to reflect an open truck flow from mixing center to port of loading *i*

Objective Function:

$$\min Z = \sum tc_{SW,MC} \,.\, tf_{SW,MC} + \sum rc_{SW,MC} \,.\, rf_{SW,MC} + \sum tc_{MC,POL} \,.\, tf_{MC,POL} + \sum rc_{MC,POL} \,.\, rf_{MC,POL} + \sum oc_{POL,POD} \,.\, of_{POL,POD} + \sum opc.\, Open_{MC} + \sum Ce\left(\frac{D_{POD} \,.\, R_{POD}}{2} + k \,.\, \sigma_{POD} + D_{POD}.\, L_{POD}\right)$$

Subject to:

$$\sum tc_{SW,MC} + rf_{SW,MC} = Supply_{SW} \qquad ; \ \forall\, SW \in SWs$$

$$\sum POD_{POL,POD} = Demand_{POD} \quad ; \ \forall\, POD \in PODs$$

$$\sum tf_{SW,MC} + \sum rf_{SW,MC} = \sum tf_{MC,POL} + \sum rf_{MC,POL} \ ; \ \forall\, MC \in MCs$$

$$\sum tf_{MC,POL} + \sum rf_{MC,POL} = \sum of_{POL,POD} \quad ; \ \forall\, POL \in POLs$$

$$\sum Open_{MC} = 1 \ (Open\ only\ 1\ MC)$$

$$\sum RailOpen_{SW,MC} + \sum TruckOpen_{SW,MC} = 1\ ;\ \ \forall\, SW \in SWs\ |\ MC\ \in MCs$$

$$\sum RailOpen_{MC,POL} + \sum TruckOpen_{MC,POL} = 1\ ;\ \ \forall\, MC \in MCs\ |\ POL\ \in POLs$$

$$rf_{SW,MC}\ \le\ RailOpen_{SW,MC}\ \times\ 999{,}999\ ;\ \ \forall\, SW \in SWs\ |\ MC\ \in MCs$$

$$rf_{MC,POL}\ \le\ RailOpen_{MC,POL}\ \times\ 999{,}999\ ;\ \ \forall\, MC \in MCs\ |\ POL\ \in POLs$$

$$tf_{SW,MC}\ \le\ TruckOpen_{SW,MC}\ \times\ 999{,}999\ ;\ \ \forall\, SW \in SWs\ |\ MC\ \in MCs$$

$$tf_{MC,POL}\ \le\ TruckOpen_{MC,POL}\ \times\ 999{,}999\ ;\ \ \forall\, MC \in MCs\ |\ POL\ \in POLs$$

$$L_{POD} = \sum RailOpen_{SW,MC} \,.\, L_{SW,MC} + \sum TruckOpen_{SW,MC} \,.\, L_{SW,MC} + \sum RailOpen_{MC,POL} \,.\, L_{MC,POL} + \sum TruckOpen_{MC,POL} \,.\, L_{MC,POL} + \sum L_{POL,POD}\ \ ;\ \ \forall\, SW \in SWs\ |\ MC\ \in MCs\ |\ POL\ \in POL$$

3.3.1 Flexibility

We have incorporated the option of transporting goods through truck or rail from the supply warehouse to the mixing center and from the mixing center to the port of loading. The results of the analysis will be found in chapter 4.3.

4 Results

The results chapter starts with the data collection that we got from the CPG company. In this process, we analyzed the available information and performed visualizations in Power BI to get a perspective on the current export supply chain of the company. Later, we present the results of the outcome of the center of gravity analysis and the proposal for the grouping of the ports of discharge. After that, we present the Mixed Integer Linear Programming model and the sensitivity analysis.

4.1 Data Collection and Analysis

Before going into the details of any proposed technique to solve the problem of the company, we focused on collecting and understanding the available data. We built visualizations in Power BI to better understand the current volume flow, container distribution by port, volume by port of discharge, and the costs perspective. This data analysis helped to ask clarifying questions to the company contact and recommend next steps according to the available information. This analysis was also helpful to identify outliers in terms of ocean freight cost of containers from North America to different ports of discharge in Latin America.

We built visualizations to understand the current perspective of the supply chain of the CPG company. Using Power BI of Microsoft, we performed the analysis of the information about volume, port of loading, and port of discharge provided by the company (Figure 13).

In order to understand the current perspective of costs, we also analyzed the cost information where we found a noticeable increase in prices of 15% on average compared with the previous year's negotiation as shown in Figure 14. Also, we found that the increase in the transportation rates varies considerably depending on the lane and the equipment type as shown in the figure.

Figure 13 Volume Perspective by Country, Port of Load, and Port of Discharge

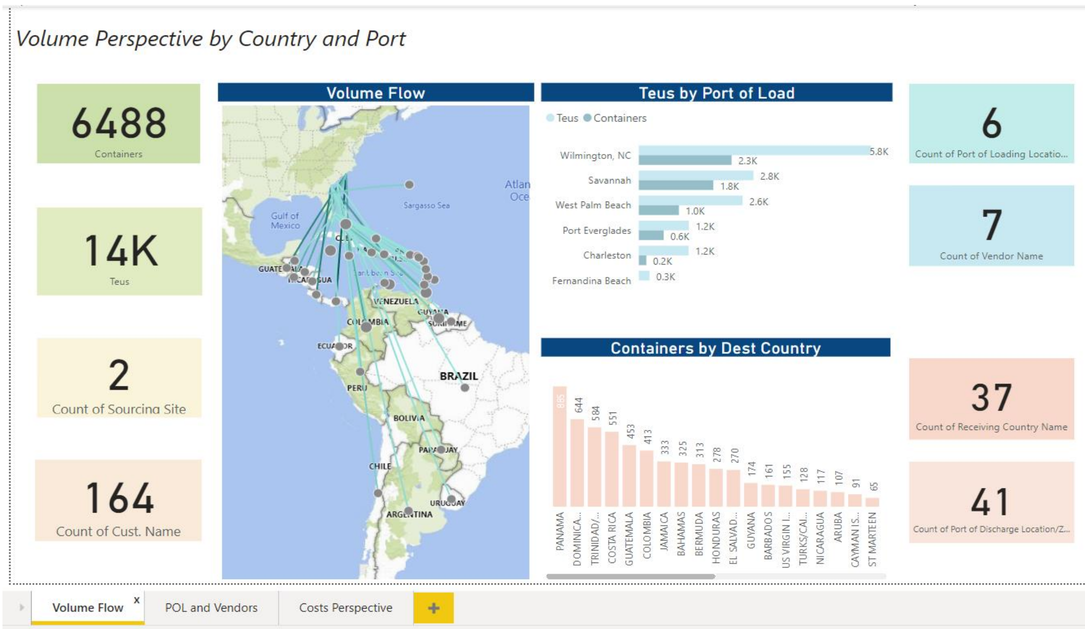
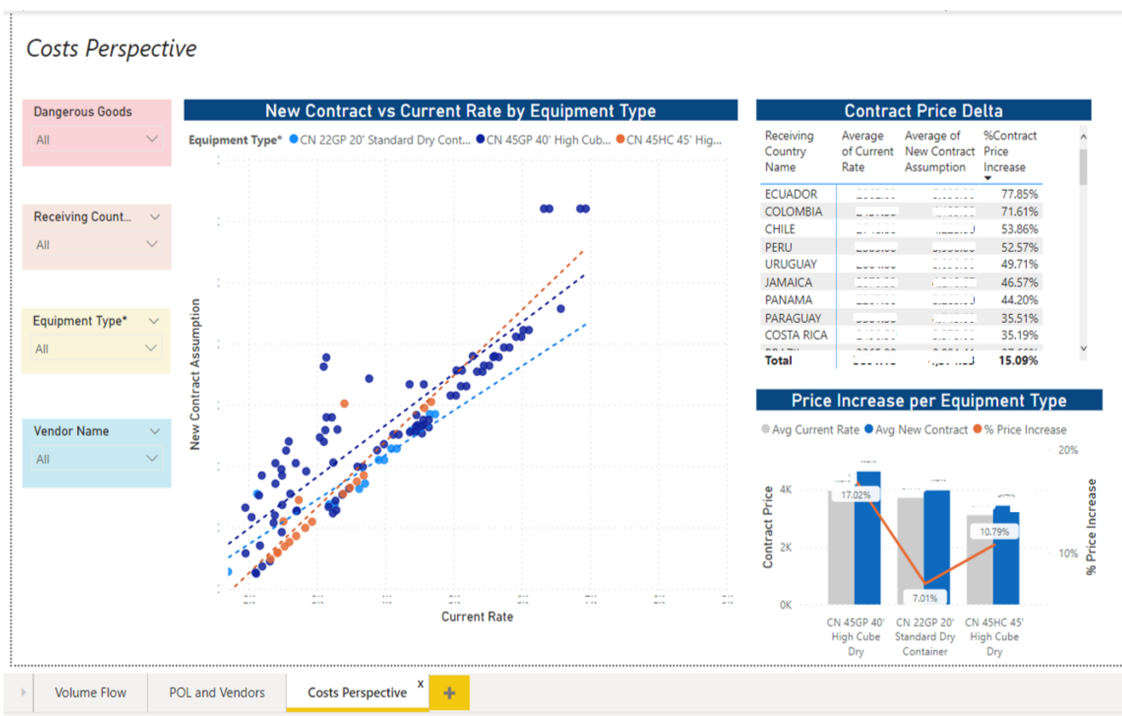


Figure 14 Costs Perspective



4.2 Outcome of the Supply Chain Performance Analysis

Given the data provided by the CPG company and the proposed methodology, we performed a Center of Gravity analysis for the mixing center location and for the consolidation of shipments to the Caribbean Islands which can be found in the following chapters.

4.2.1 Center of Gravity - Mixing Center Location

In order to recommend the optimal location for the mixing center, it was necessary to compile the data of the current supply warehouse and the existing ports of loading. Using the coordinates and the existing volume per facility, the new optimal location of the mixing center should be close to the ports of loading. The specific location according to the COG is South Carolina, compared to the existing location of the mixing center in North Carolina.

4.2.1.1 Port of Discharge Grouping

Considering the current container fill rate (60% average shared by the CPG company contact) of the shipments to the Caribbean islands, we proposed a shipping consolidation in one of the islands to reduce the impact of container utilization and sustainability. In this case, we performed a COG analysis of the eastern islands of lower volume to recommend consolidating volume in one island and avoiding inefficient containers that affect the cost and the traveled distance. The outcome of this analysis was the consolidation in Dominica island of the volume of Barbados, St Maarten, British Virgin Islands, St Barthelemy, Saint Lucia, Antigua and Barbuda, Grenada, St Vincent, and Anguilla.

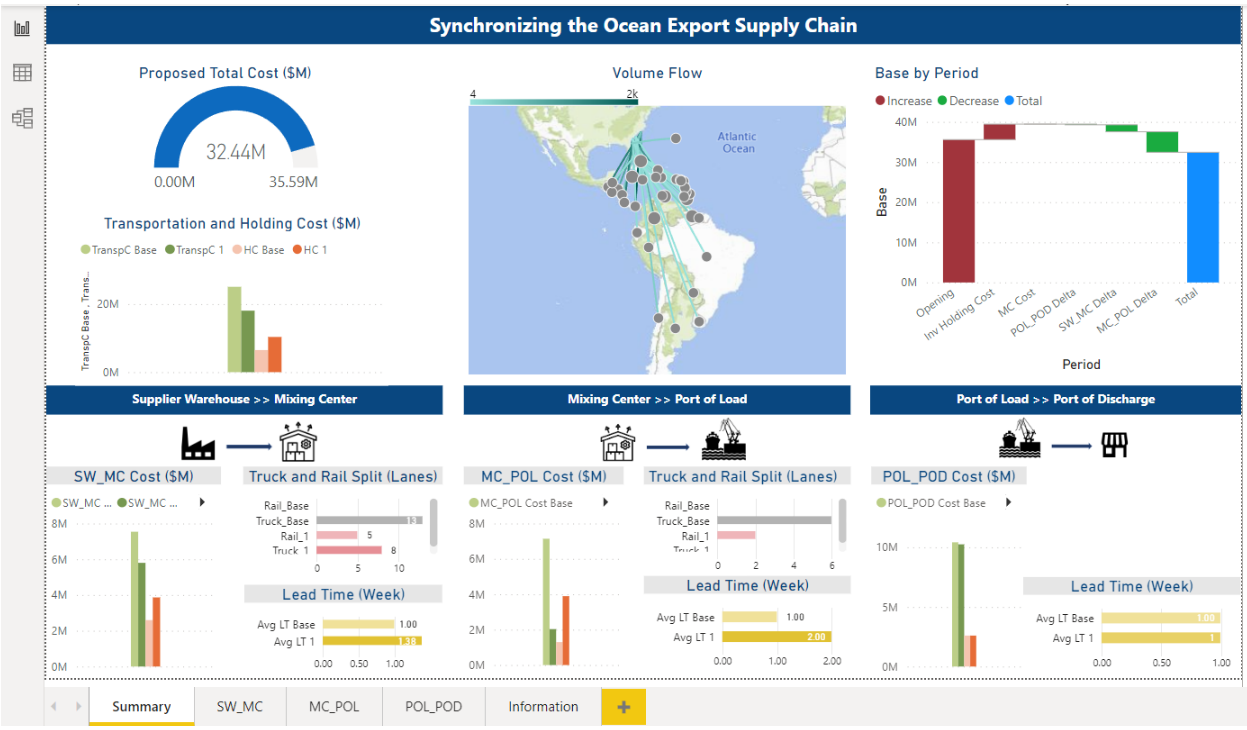
4.3 MILP Model

After performing the MILP model using Python and the Gurobi optimization package, we got the optimal volume flow from the supply warehouses to the mixing center, from the mixing center to the ports of loading, and from the ports of loading to the ports of discharge considering the current data of volume, costs, lead time, and expected service level of the company.

In order to perform an analysis of the results, we built a visualization dashboard using Power BI that provides the perspective of the optimal supply chain design. Figure 15 shows the summarized perspective of the current scenario of the CPG company and an optimal scenario from the MILP modeling with the Gurobi optimization package used in Python. In a similar way, the CPG company will have the perspective of the detailed information on the optimal supply chain from the supply warehouse to the mixing center, from the mixing center to the ports of loading, and from the ports of loading to the ports of discharge.

Figure 15 presents the comparison of the total costs from the supply warehouses to the mixing center, from the mixing center to the ports of loading, from the ports of loading to the ports of discharge; inventory holding cost, and the cost of running the proposed mixing center by the MILP model. This information is presented for the proposed scenario compared to the current perspective of the company.

Figure 15 Summary of Base Scenario Compared to Optimization Scenarios

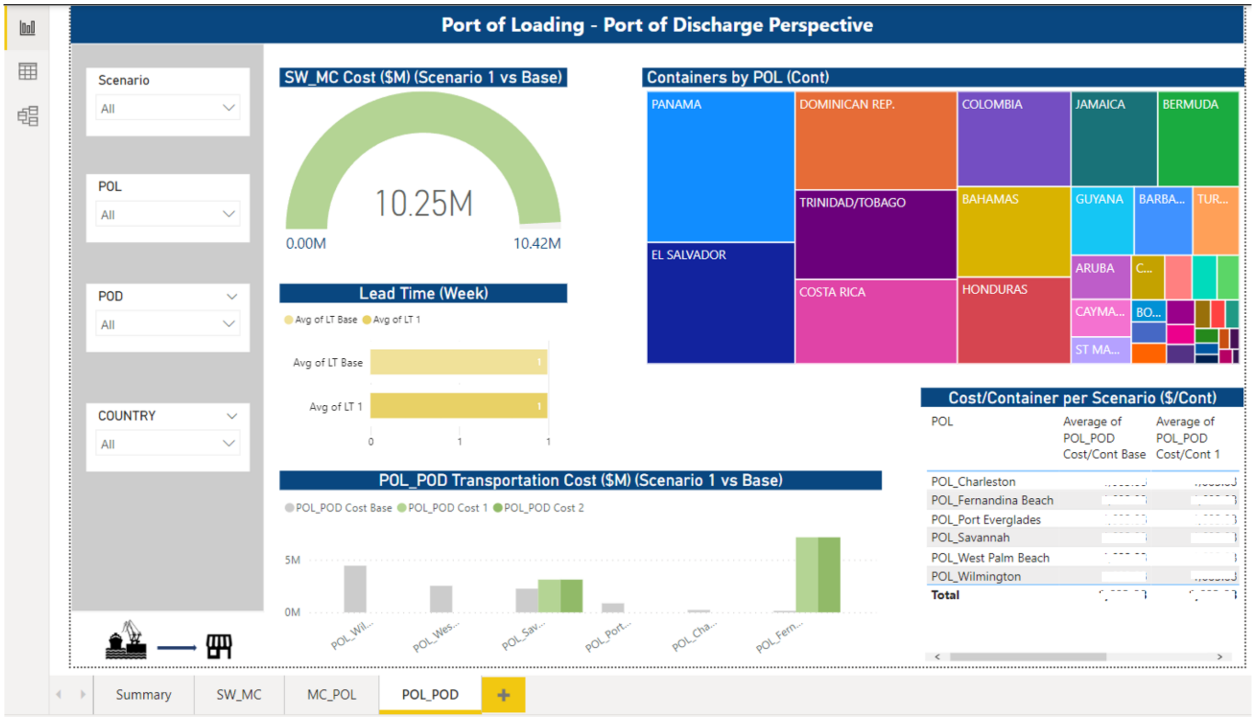


In order to provide the ability to analyze more detailed information about each part of the supply chain, we included additional tabs to analyze more specific information from the supply warehouse to the mixing center (Figure 16), from the mixing center to the port of loading (Figure 17), and from the port of loading to the port of discharge (Figure 18).

Figure 16 Summary of Supply Warehouse to Mixing Center Perspective

Figure 17 Summary of Mixing Center to Port of Loading Perspective

Figure 18 Summary of Port of Loading to Port of Discharge Perspective



4.4 Sensitivity Analysis

There are multiple variables in the MILP model that supply chain decision-makers can intervene in, namely holding cost, transportation cost, and mixing center cost. All of these three factors can improve through negotiation. In addition, holding cost can be reduced by better warehouse design, upgraded warehouse management system; transportation cost can be reduced by more efficient vehicles; mixing center can be reduced by upgrading mixing equipments. Given limited company resources, a sensitivity analysis is performed to help decision-makers prioritize their investments for the most notable supply chain network improvement. For each model iteration, only one variable from the base case is modified to a range from 50% to 150% of base case value, while the rest of the variables are kept constant at base case value.

Figure 17 shows the result for sensitivity analysis of holding costs, transporation cost, and mixing center cost. The gradient of lines represents the sensitivities of variables. The result shows that holding cost SW_MC and mixing center cost are the most sensitive factors, followed by transportation cost, holding cost POL_POD, and the least sensitive factor is holding cost MC_POL. It implies that the company should spend most resources on improving holding costs from supply warehouse to the mixing center, and on reducing mixing center operation cost.

Note that the sensitivity analysis lines are not always straight. The inflection points represent a change in route choice, be it transportation mode, mixing center location, or volume allocation.

Besides, the base case MILP model used a truck-to-rail transportation cost ratio of 3, meaning the transportation cost of truck is 3 times as expensive as rail. Another sensitivity analysis is conducted to test the robustness of our supply chain cost with respect to the transportation cost ratio. Figure 18 shows that the change in supply chain cost decreases as the truck-to-rail transportation cost ratio increases. This aligns with our expectation as at a ratio of 3, most of the optimized transportation mode is already rail, and there is not much leeway for the model to switch from truck to rail to further reduce transportation cost as the ratio increases.

Figure 19 Sensitivity Analysis of holding costs, transportation cost, mixing center cost

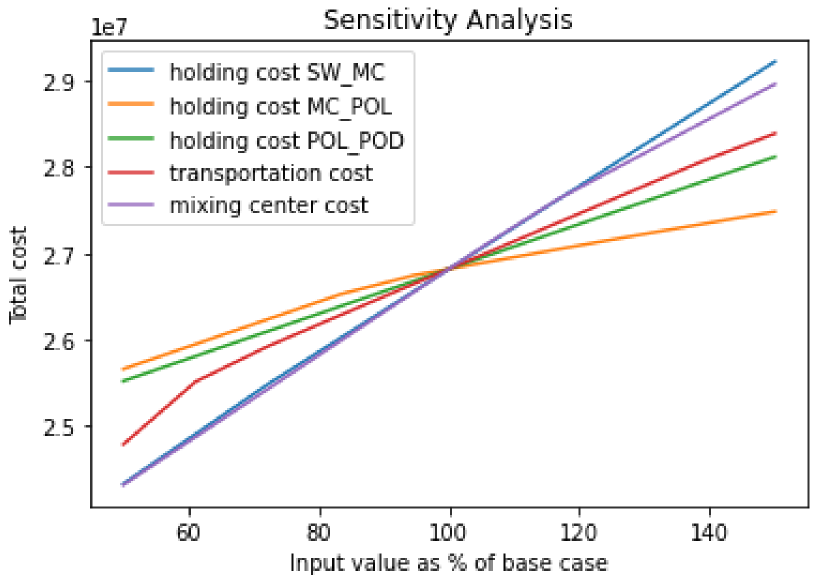
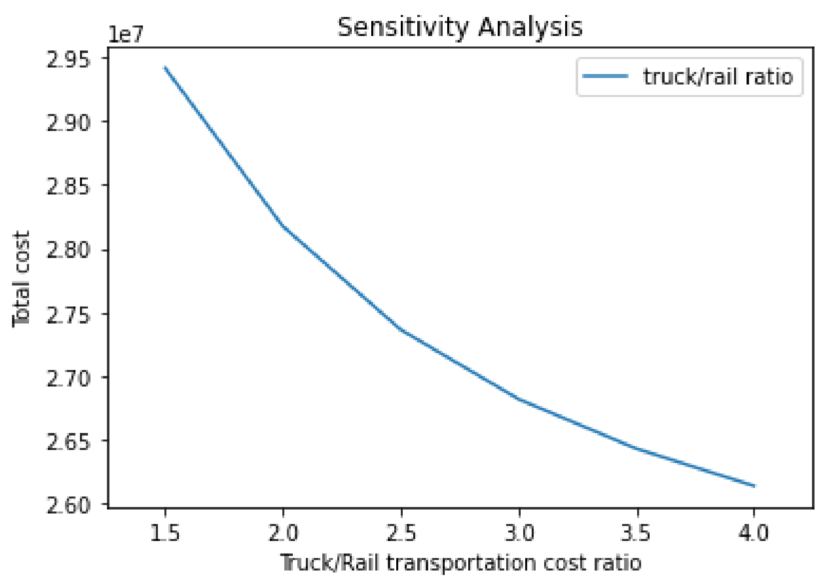


Figure 20 Sensitivity Analysis of truck-to-rail transportation cost ratio



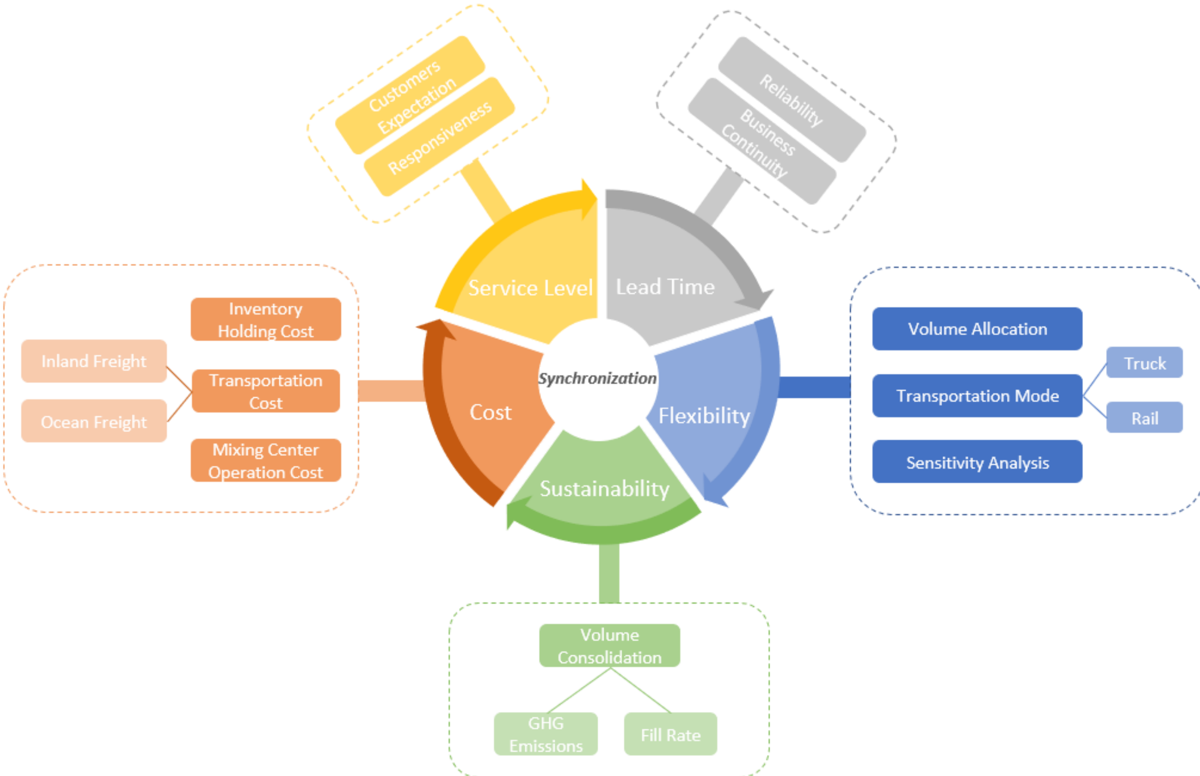
5 Discussion

5.1 Insights and Managerial Implications

This project offers a framework that addresses such main factors as costs, lead time, service level, flexibility, and sustainability to help companies identify the optimal network design from supply warehouses to mixing centers, ports of loading, and ports of discharge. The graphical representation of this framework can be found in Figure 21.

The proposal to the CPG company represented an optimal volume allocation based on our model recommendation, which also suggests changes in transportation modes from truck to rails in certain routes from the supply warehouses to the mixing center and from the mixing center to the ports of loading. It is worthwhile to add flexibility to the supply chain by introducing different transportation modes. This validates that managers should find the tradeoff between transportation and inventory holding costs.

Figure 21 Synchronization Framework



The modeling of the MILP to optimize the volume allocation provides versatility for companies to change assumptions and anticipate the impact of potential adjustments to the supply chain. When we ran different scenarios, we found that the CPG company has an opportunity of reducing by 9% their costs. In this optimal scenario we found that in order to optimize the supply chain costs for the CPG company, we need to propose a new tradeoff between the transportation and the inventory holding costs. In the optimal scenario, the transportation costs were reduced by 28%. This transportation cost was mainly reduced by the change in transportation mode of the inland freight from trucks to rail in certain routes from the supply warehouses to the mixing center, and from the mixing center to the ports of loading. While this new volume allocation contributed positively from the transportation point of view, it impacted the inventory holding cost with an increase of +60% of the inventory holding cost. Given the supply chain of the inland freight using rails compared to trucks for certain routes, this optimal solution had also an impact on the lead time of +0.38 weeks from the supply warehouse to the mixing center and +1 weeks from the mixing center to the port of loading. However, overall the savings in transportation offset the impact of the inventory holding cost with the increased lead time.

We also tested the robustness of the supply chain costs with respect to the transportation cost ratio through the sensitivity analysis. We found that the variation in supply chain cost decreases as the truck-to-rail transportation cost ratio increases. Our results also showed that holding cost from the supply warehouses to the mixing center and mixing center cost are the most sensitive factors, followed by transportation cost, holding cost from the ports of loading to the ports of discharge, and the least sensitive factor is holding cost from the mixing center to the ports of loading. This suggests that the company should spend most resources on improving the holding cost from supply warehouse to mixing center, and on decreasing the mixing center operation cost.

From the sustainability point of view, we analyzed the grouping proposal of the ports of discharge in the Caribbean islands. This represents an opportunity for the company to increase container utilization and reduce the sustainability impact as a consequence of the emissions due to inland freight and ocean transportation. We recommend that the company pays attention to the container fill rate and consider the consolidation of volume when possible to decrease the costs, reduce the traveled distance, and ultimately minimize the impact on the environment.

5.2 Limitations and Directions for Future Research

Given the computational and business-process complexity that arises from the multicriteria nature of the problem under consideration, this study has certain limitations. The sustainability was incorporated as part of simulation scenarios of ports of discharge grouping to reduce the traveled distance and decrease the emissions. Although we also contributed to the sustainability of the business by reducing costs through inventory and commodity flow optimization, there is an opportunity to incorporate the sustainability impact as an outcome of the model when evaluating different transportation modes. The impact on the environment can be incorporated in future research for companies to decide if they are willing to pay more to avoid the impact of the emissions due to inland and ocean transportation.

6 Conclusions

Increasing ocean freight cost and volatility have raised global attention. Many multinational companies are looking to offset the rising cost with ocean export supply chain efficiency and synchronization improvements. This project aims to provide a framework for companies to drive synchronization in their ocean export supply chain.

The literature on ocean freight and synchronization highlighted several important factors for ocean supply chain synchronization: transportation cost, inventory holding cost, transportation lead time, service level, flexibility, and sustainability.

This project studied synchronization problem with data from a leading FMCG company. Descriptive data analysis and data visualizations established a complex supply chain network with 62 nodes, 284 possible arcs, and 6488 container shipments per year. In addition, ocean freight cost analysis validated a significant price increase of 15% from last year for the capstone company.

We carried out an initial assessment of the current mixing center location in North Carolina with a center of gravity analysis. This analysis showed that the optimal mixing center location is in South Carolina, which is very close to the current location, but closer to the ports of loading.

This study concluded that companies could reap financial benefits by locating mixing center closer to ports rather than supply warehouses since ports are notably less scattered than supply warehouses.

Next, we carefully designed a MILP model to recommend mixing center location and shipping routes for the capstone company to optimize its overall supply chain cost including transportation cost, inventory holding cost, and mixing center cost. The rail option is added to the existing truck option for inland transport from the supply warehouse to ports of loading. Having multiple modes of transportation adds flexibility to the model, the model also proved that a synchronized ocean export supply chain design could reduce the overall cost by 9%.

Considering that the company has many decisions to make along the supply chain but limited resources on hand, we conducted a sensitivity analysis of the MILP model to identify the most effective points of intervention. We recommended the company to work on holding cost from supply warehouse to mixing center and mixing center cost first, followed by transportation cost, holding cost from ports of loading to ports of discharge, and leaving holding cost from mixing center to ports of loading at last because this is the least sensitive factor.

While this capstone project addressed the supply chain synchronization problem at a specific company, the methodology can be implemented in other multinational companies, and the model can be flexibly adapted with different companies' data. In summary, the project suggested that significant cost savings could be realized through ocean export supply chain synchronization; companies must challenge the status quo and leverage quantitative models to consider possible supply chain network design options for improved synchronization.

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Appendix A: Mixed-Integer Linear Programming Model

The mixed-integer linear programming model built-in Python can be easily updated with the latest freight information for sponsor company to optimize transportation routes in the future.

Input files include 5 csv files:

1. Coordinates.csv

   Column A: name of node (Supply warehouse SW / Port of Loading POL / Port of Discharge POD)

   Column B: latitude and longitude of node

2. Cost at MC.csv

   Column A: name of mixing center

   Column B: yearly operating cost at mixing center

3. Demand at POD.csv

   Column A: name of port of discharge POD

   Column B: demand at port of discharge POD

4. Ocean freight cost.csv

   Column A: name of port of loading POL

   Column B: name of port of discharge POD

   Column C: ocean freight rate from POL to POD

5. Supply at SW.csv

   Column A: name of supply warehouse SW

   Column B: supply at supply warehouse SW

Output file is 1 xlsx file:

1. Output_flow.xlsx

   Column A: name of origin node (Supply warehouse SW / Mixing Center MC / Port of Loading POL)

   Column B: name of recipient node (Mixing Center MC / Port of Loading POL / Port of Discharge POD)

   Column C: Volume of truck transportation in containers

   Column D: Volume of rail transportation in containers

   Column E: Volume of ocean transportation in containers

The output file is then fed into the PowerBI spreadsheet for visualization (See Appendix 2).

Appendix B: Model Visualization in Power BI

The visualizations in Power BI can be updated with the latest model already performed in Python.

Input the following tabs:

1. Supply

   Column B: Update the supply (in containers) from each supply warehouse of the base scenario in Column B.
2. Demand: Update the demand (in containers) of each port of discharge in Column B.
3. Ocean_Freight_Costs: Update the cost per container from each port of loading to each port of discharge in Column C.
4. Coordinates: Update the coordinates for each supply warehouse, mixing center, port of loading, and port of discharge in Column B.
5. MC_Cost: Update the cost of running each mixing center in Column B.
6. SW_MC: Update the information from the supply warehouse to mixing center for each scenario:
   a. Containers: Update the number of containers from each supply warehouse to each mixing center in Column D.
   b. Truck/Rail: Based on the recommendation of the Python model, update if the volume from the supply warehouse to the mixing center is recommended by "Truck" or "Rail" in Column E.
   c. SW_MC Cost/Cont: Update the inland rate from each supply warehouse to each mixing center in cost per container in Column H.

(Please note that yellow columns are the ones that need an update)

7. MC_POL: Update the information from mixing center to port of loading for each scenario:
   a. Containers: Update the number of containers from each supply warehouse to each mixing center in Column D.
   b. Truck/Rail: Based on the recommendation of the Python model, update if the volume from the supply warehouse to the mixing center is recommended by "Truck" or "Rail" in Column E.
   c. MC_POL Cost/Cont: Update the inland rate from each mixing center to each port of loading in cost per container in Column H.
   d. LT: Update the lead time in Column J.
8. POL_POD: Update the information from port of loading to port of discharge for each scenario:
   a. Containers: Update the number of containers from each port of loading to each port of discharge in Column H.
   b. POL_POD Cost/Cont: Update the inland rate from each port of loading to each port of discharge in cost per container in Column I.
   c. LT: Update the lead time in column K.
   d. LT: Update the lead time in Column J.
9. Calculation: Update the information on transportation cost, mixing center cost, and holding cost for each scenario from Column B to G. This information comes from the Python model outcome.

10. DB: Update the rate of truck vs rail transportation costs for each scenario in Column E and Column F.
11. When all the information is saved in the file, click “Refresh” in the Power BI dashboard and review the data.