What makes beauty more beautiful?

Botanical Supply Chain Network Optimization

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ABSTRACT
The beauty and personal care industry has undergone significant changes in recent years, with consumers becoming increasingly concerned about the ingredients used in their skincare products. There has been a growing preference for natural and organic ingredients, with many consumers looking to avoid products that contain harsh chemicals or synthetic ingredients. As a result, many consumer product goods (CPG) manufacturers, including Company A, have begun to develop new product lines that contain natural botanical ingredients. For our Capstone, Company A is looking for ways to evaluate and upgrade its procurement and logistics operations for natural botanical ingredients, with the ultimate goal of designing an efficient and eco-friendly supply chain. To achieve this goal, the Capstone project focused on two key areas: supplier optimization and route optimization. The first objective was to assess the current supply chain network to provide visibility on its performance and identify areas for improvement. The second objective was to formulate recommendations for redesigning the current supply chain network with the goal of decreasing travel distances and reducing environmental impact. To address these objectives, the project utilized various analytical tools, including Excel, Power BI, and Python. The team analyzed Company A's data and characterized current operations using various statistical analyses. The team also used a network design model based on the transshipment problem to connect supply, transfer, and demand sites. Finally, the project used an environmental impact evaluation feature to estimate the carbon footprint of each route in a given network. In summary, the project focused on two key areas: supplier optimization and route optimization. Using various analytical tools, the project identified areas for improvement and formulated recommendations for redesigning the current supply chain network to reduce travel distances and environmental impact. Ultimately, the project provides clear strategic directions for improving the supply chain network for natural ingredients in Company A's beauty business.

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1 INTRODUCTION

1.1 Project Background

The Company A is a multinational CPG (Consumer Product Goods) manufacturer, which produces various kinds of skincare products. One of the most outstanding trends in skincare products is the increase in consumer awareness and preferences for natural materials as consumers put more value on a healthier life according to the survey by McKinsey's survey (2022). CPG manufacturers have introduced many new product lines and various products that contain natural botanical ingredients with wellness features. The Company A is also reviewing its product portfolio with these considerations.

Natural botanical ingredients represent several challenges compares to traditional ingredients. Chemical materials are typically manufactured in the factory with foreseeable circumstances and thus more controllability over sourcing the raw materials, quality control, and capacity control. Natural botanical ingredients require more complex operations due to the limited and fragmented feedstock harvesting, perishable characteristics, and specific methodologies for processing them into certain forms: oil, powder, etc. Some examples of these complexities are the unexpected incidents such as storms and drought, which could impact the whole supply chain network, and short shelf-life requires more timeliness in logistics. The complexity of the operations regarding natural ingredients sourcing has further increased due to the lingering effects of the COVID-19 pandemic on global supply chains (e.g., supply chain disruptions, port congestions). Consequently, final good manufacturing with scale could be affected seriously by inconsistent procurement of natural botanical ingredients.

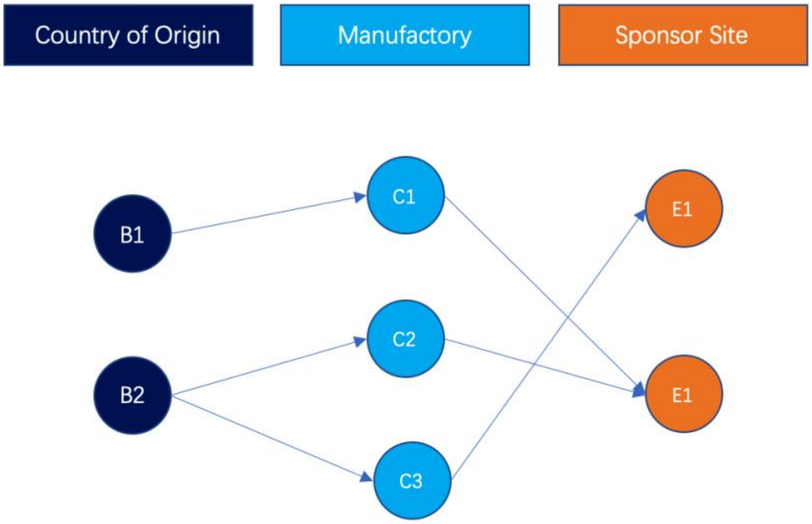
In addition, consumers have a growing concern about the environmental sustainability of what they purchase, use, and eat. B2C (Business-to-Consumer) companies, such as Company A, have stronger incentives to implement more eco-friendly supply chain operations to meet the expectations of consumers. (Stefan, H. et al (2012)

In this context, Company A is looking for ways to 1) evaluate its procurement and logistics operations for natural botanical ingredients, and 2) upgrade its supply chain network to make it efficient and eco-friendly in the future.

1.2 Overview of the current operations

Company A is currently operating a supply chain network to procure natural botanical ingredients that will be put into hair and skincare products. Figure 1 provides an overview of this network.

Figure 1 Current Company A Supply Chain Network



The network under consideration consists of three types of nodes:

- Countries of origin: these are the starting point of flows where raw materials are harvested and collected. Raw materials are currently procured from over 50 countries across 5 continents.

- Manufacturing locations: these are the intermediate point of flows where contract manufacturers (CMs) turn the raw materials into semi-finished products of various types (e.g., powder, liquid, oil) to prepare for the final process. Right now, there are 28 contract manufacturers located in 12 countries.

- Company A’s sites: these are the end point of flows where Company A produces the finished products ready for delivery. As of now, Company A has 30 sites serving different markets located in 17 countries.

We can note that the location of final delivery points (i.e., Company A’s customers) is outside of the scope of this Capstone. All the materials are supplied through this network. These materials consist of fruits, flowers, and plants like roses, aloe, avocado, etc. Each material can have one or several countries of origin. For example, suppliers located in both Morocco and Pakistan supply roses to manufacturers.

Different modes of transportation are used for supplying goods throughout this network:

- Connections between countries of origin and manufacturers are established through sea freight or land (trucks)

- Connections between manufactories and Company A sites is done through airfreight, sea freight, or land (trucks)

The company wishes to redesign its network to minimize traveled distances and costs, with the following constraints:

- Company A site locations are fixed; in addition, the demand of each Company A site for each material is fixed, as it depends on the demand of the markets served by the Company A site.

- Countries of Origin are fixed; in addition, the supply of each origin location for each material is fixed, as it depends on the available raw materials in each country of origin.

Consequently, the main changes in the network configuration consist of changes in the manufacturing locations for different products (i.e., using a different manufacturer for processing certain materials) and changes in the flows between countries of origin and manufacturers and between manufacturers and Company A sites.

1.3 Problem Statement and Objectives

The main goal of the research is to determine how Company A can design a sustainable and cost-efficient effective supply chain for procuring natural botanical ingredients. To achieve this goal, the project focused on two key areas: (1) supplier (i.e., manufacturer) optimization, which consists of determining the optimal locations of manufacturers used to procure goods, and (2) route optimization, which consists of identifying the optimal routes connecting different nodes of the network. The overarching objective was to establish a network design with the goal to reduce total travel distances, shipping costs and CO_2 emissions, in line with Company A's instructions.

The Capstone project consists of several objectives:

- Objective 1: Assessing the Current Supply Chain Network to provide visibility on the current network performance and identifying the key areas for improvement
- Objective 2: Formulating Recommendations for redesigning the current supply chain network to decrease travel distances and reduce environmental impact

Each of these objectives corresponded to specific methodologies.

- To address objective 1, we analyzed Company A's data and characterized current operations using various statistical analyses.

- To address objective 2, we used the following tools:
    - Network design model, which is based on the transshipment problem. This model aimed to connect the supply, transfer, and demand sites in a balanced manner. The model considered the locations of different nodes in the network and ensured that there will not be inefficient routes, such as detours (e.g., a material sourced from China, brought to North America for initial processing, and then moved to China again for final goods manufacturing).
    - Environmental impact evaluation feature, which allows to analyze the environmental footprint of the resulting network, by characterizing the carbon footprint of each route, accounting for traveled distances and mode of transportation.

1.4 Structure of the report

This report is structured as follows. Chapter 2 focuses on a literature review that aims in identifying tools and methodologies useful to achieve the aforementioned objectives. In Chapter 3, we discuss the methodology that we used to conduct the literature review and address the problem and objectives. In Chapter 4, we present the results from the analysis of the current supply chain network and the results from the optimization model that was developed. In Chapter 5, we derive a conclusion based on the results from the previous chapter. In Chapter 6, we discuss recommendations and limitations for the project.

2 STATE OF ART

To address the main problems of our project— to evaluate the performance of the current supply chain network for natural ingredients in Company A Beauty's business and identify areas for improvement, with the ultimate goal of redesigning the network to reduce travel distances and environmental impact—we reviewed the literature in several areas.

To fulfill Objective 1 of our Capstone project, which involves evaluating the current network and identifying areas for improvement, we conducted a brief literature review of statistical methods used to characterize network performance. Results are presented in Section 2.1.

To tackle Objective 2 of our project, which involves designing an optimized supply chain network with environmental considerations, we proceeded in two steps. We first conducted a review of the literature on supply chain network design with manufacturer selection. A summary of our review is presented in Section 2.2. We then reviewed methods allowing us to assess the environmental impact of different routes and networks. Details of our findings are reported in Section 2.3.

2.1 Statistical Analysis for Supply Chain Network Evaluation

The literature on statistical analysis for supply chain networks focuses on methods that allow for the characterization and evaluation of network performance. Two relevant, well-established approaches are useful for our project. We present these in the following.

The first approach is descriptive statistical analysis, which employs various statistical measures (e.g., mean, median, and standard deviation), to provide a summary of network data. These statistical measures can be used to identify trends, patterns, and anomalies in the data, and can provide insights into the performance of the network (Nick, 2007). For a review of some commonly used methods and measures, we refer the reader to (Fisher & Marshall, 2009).

The second approach is to use statistical models to analyze the data and make predictions about network performance. For example, regression analysis can be used to identify the relationships between different variables in the network, such as shipping distance, shipping volume, and shipping frequency, and to predict the impact of changes in these variables on network performance (Davison, 2003). In the context of our Capstone, regression analysis was used to establish a correlation between travel distances and costs, travel volumes and costs. Our objective was to infer generalizable relations between these elements that we could further use in our network model. This is a well-established approach in the literature. Several contributions use this method to establish such relationships (see e.g. Gouvernal & Slack, 2012).

2.2 Supply Chain network design with manufacturer location selection

Our problem consists in selecting manufacturers' locations for the supply chain network. An appropriate location determination needs to consider both the qualitative and quantitative nature of information (Townroe, 1972). There are two main streams in the literature in this area, focusing on these two aspects.

The first stream focuses on factors that impact the attractiveness of manufacturer locations. Deciding to select the location of a production or a manufacturing plant is very important, both from a business and economic perspective. The location of the plant determines the shipping distance (for raw material from the origin and finished product to the downstream), and impacts elements such as available workforce skill, or the cost of labor operation. (Brush et al., 1999). We also found several contributions which examined the location of manufacturers' geopolitical concerns (see e.g., (Moradlou et al., 2021). Since Company A did not provide a complete dataset that would allow us to assess these elements due to confidentiality concerns, the selection of manufacturer locations based on their characteristics was not possible. We therefore focused our review on the second stream of literature, i.e., the network design problem with manufacturer location selection.

The second approach involves examining the locations of manufacturers from the point of view of the overarching network design. The goal is to identify suitable locations that can yield the optimal performance of the supply chain network in terms of various dimensions, such as cost, travel distances, or environmental impact. A network design optimization model is a mathematical framework that uses mathematical equations, decision variables, constraints, and an optimization algorithm to find the best possible design and configuration of a network, with a specific objective in mind. It helps decision-makers make informed decisions about the design and layout of networks to achieve desired outcomes efficiently and effectively (Dondo et al., 2009).

The literature in this field is extensive, with numerous studies and research papers. A search of "network design" yields a significant number of results. To gain a comprehensive understanding of the literature, we referred to in-depth reviews by established researchers in the field (see e.g., Farahani et al., 2014). The most common approach in this field is to use integer programming, a mathematical optimization technique that deals with decision variables that must take on integer values (Kamyabi et al., 2022). It is a subset of linear programming (LP), where the additional constraint of integer values for decision variables is imposed. IP is used to model and solve discrete optimization problems in various fields, such as operations research, logistics, supply chain management, and finance, among others.

There are several, well established, mathematical models in this space. We review the two most relevant for our purposes: (1) Facility Location Problem (FLP) and (2) Transshipment problem.

The Facility Location Problem was defined by (Daskin, 1997). It is a classic optimization problem that involves determining the optimal location of facilities or service points to minimize costs or maximize efficiency. It is typically used in logistics, operations research, and supply chain management. The objective of the FLP is to select the optimal locations for facilities from a set of candidate locations, taking into consideration factors such as transportation costs, demand, capacity, and location-specific constraints. An extensive review of facility location problems has been made by Melo et al. (2009). The simplest setting of such a problem is the one in which p facilities are to be selected to minimize the total (weighted) distances or costs for supplying customer demands. This is the so-called p-median problem which has attracted much attention in the literature (see, e.g. Daskin, 1997). The common characteristic of these problems is to consider fixed facility costs on one or multiple facility layers. In our Capstone, although we are selecting locations of manufacturers from a given set, we are not considering any fixed costs with their activation or deactivation. Consequently, our problem can be summarized as a simple network flow problem.

For our purposes, we consider a transshipment problem as defined by (Dondo et al., 2009). This is a network flow problem with multiple layers of facilities. This is the most relevant approach since our project involves the intermediate manufacturers acting as a transfer point where material can be received from multiple sources and then shipped to multiple destinations. A transshipment problem is a type of logistics problem in which goods are transported from their initial sources to their final destinations through intermediate locations called transshipment points. The objective of a transshipment problem is to determine the optimal flow of goods between these locations while minimizing the transportation cost. In a transshipment problem, there are typically multiple sources, multiple destinations, and multiple transshipment points. Each location has a supply or demand of goods, and each transportation link between locations has a cost associated with it. The problem is to determine the optimal amounts of goods to be transported along each link so that the total cost is minimized while satisfying the supply and demand constraints. (Guinet, 2001)

2.3 Methods for assessing emissions in a given network

Nowadays, supply chain management is integrating sustainability concerns in their company to remain active in the environment and competitive in the market (Chaabane & Geramianfar, 2015). In the scope of our Capstone, we focus mainly on the environmental pillar of sustainability, expressed through CO_2 emissions.

We reviewed the literature on transportation-related greenhouse emissions, focusing primarily on how to accurately model the CO_2 emission based on the transportation modes and travel distance. We found multiple contributions focusing on various transportation modes: truck transportation, (see e.g. (McKinnon & Piecyk, 2009), sea transportation, (Yumashev et al., 2017), air transportation, (Howitt et al., 2011).

We planned to assess CO2 emission based on two criteria: Transportation modes and travel distance. We reviewed the literature on Eco Transit, integrated these factors and developed a model based on Company A's input and Andersson's (2016) methodology.

3 DATA AND METHODOLOGY

Our methodology consists of several steps for each of our two objectives. Objective 1 involves assessing the current supply chain network to identify areas for improvement. Objective 2 involves developing recommendations to redesign the network to reduce environmental impact. The overall methodology is summarized in Figures 2, 3, and 4. The whole project consists of two steps, starting with data manipulation and moving into the analysis and network optimization as shown in Figure 2. The objective 1 was addressed with the data Analysis bucket that had three sub-sections: Descriptive Analysis(3.2.1), Regression Analysis(3.2.2), and Visualization Analysis(3.2.3) as shown in Figure 3. The objective 2 was delivered by the multiple steps from adding new features to the existing dataset, network design optimization model, and to making recommendations in Figure 4.

Figure 2 Overall Workflow for Objectives

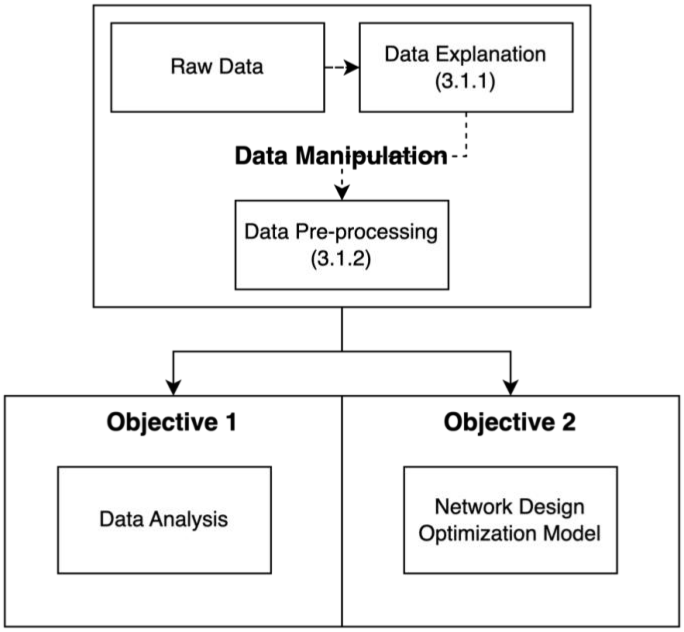


Figure 3 Workflow for Objective 1

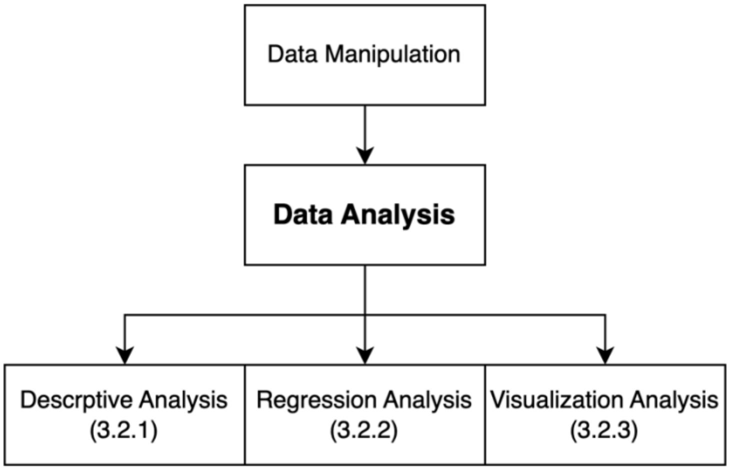
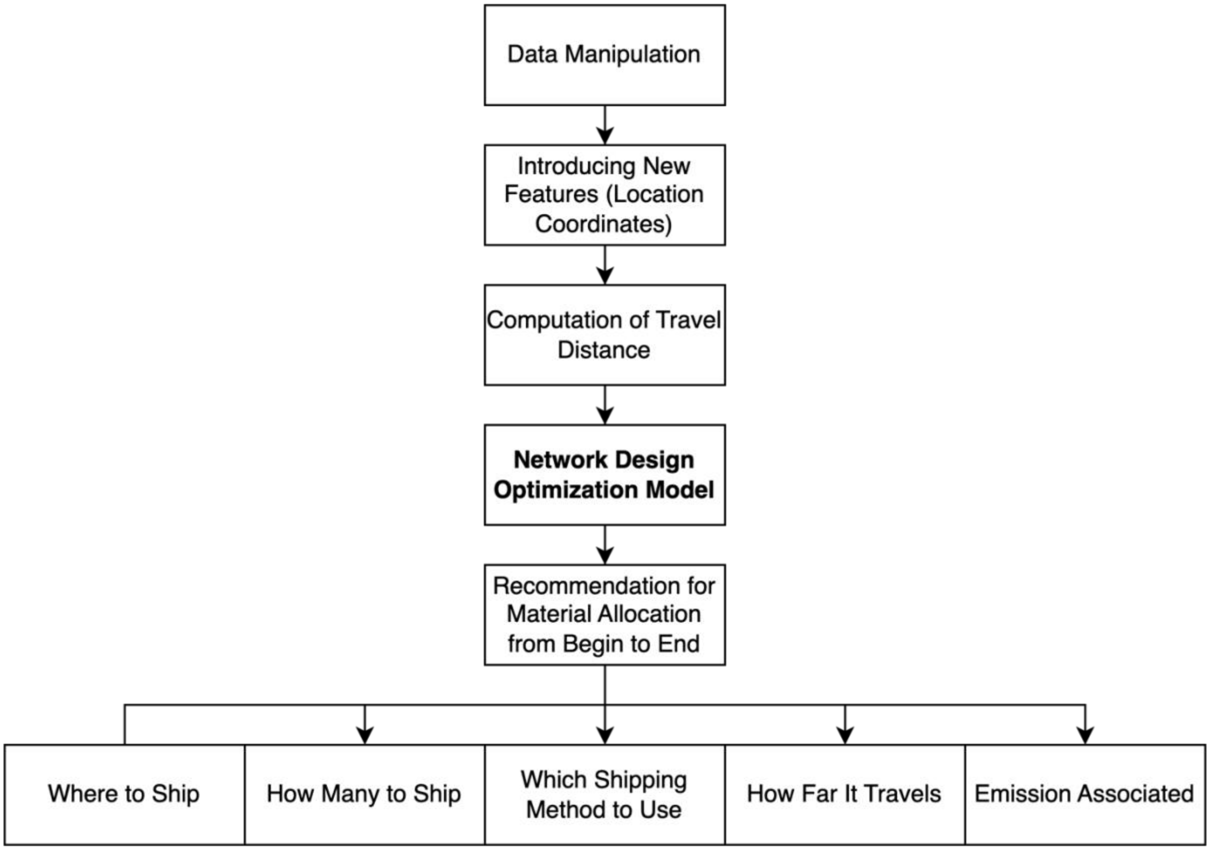


Figure 4 Workflow for Objective 2



3.1 Data Manipulation

3.1.1 Presentation of the Raw data

The raw data consisted of historical data for the years 2021 and 2022, provided by Company A. This data contains aggregate-level transactions of the botanical/ natural ingredients. Each aggregate transaction is characterized by the following fields:

- Country of origin
- Processing manufactures
- Company A sites
- Transportation modes
- Annual transportation cost
- Annual volume

The records in the dataset contain detailed information about the materials used in our supply chain. It tracks each material as it passes through various stages, from the country of origin to the processing manufacturers and eventually to the plants of Company A. Each record is unique and is based on several factors, such as the annual volume purchased, transportation modes used, and associated costs. For example, if the company sourced almond oil from Costa Rica and sent it to a manufacturing supplier in the US, but distributed it to multiple plants within our organization, each instance would be recorded as a separate row in the dataset.

3.1.2 Data Pre-processing

To have reliable data, we cleaned the data by:

- Removing non-valid records: We identified some obvious errors for the shipping cost such as empty values, negative values, and null values. We eliminated the entire row if any of these values appeared.

- Allocating materials to different origin countries: some of the botanicals have multiple countries of origin and only aggregate information on total volume is available; to allocate the volumes of these botanicals to countries of origin, we proceeded in two steps: (1) we created new rows for each of the countries of origin, (2) for each country of origin, we allocated the same amount of shipping volume (i.e., we evenly split the shipping volume for each of the locations).

After cleaning the data, we added the following additional features:

- Establishing key transportation nodes: we established a list of major ports and airports near the relevant facilities. This enabled us to be more accurate on the distance calculation since we could consider the routes covered by truck when most of the distance is covered by air freight and sea freight

3.2 Objective 1: Assessment of the Current Supply Chain Network to provide visibility on the current network performance and identify key areas for improvement.

With the given dataset, the team tried to get a clear understanding of the supply chain network's operation status in terms of geographical scatteredness and any skewness to a certain supplier or a region, and relationships between various factors. The team started with Descriptive Analysis (3.2.1) to understand the structure of the supply chain network and use it to derive a hypothesis, which aims to find potential targets for efficiencies. Then the team ran Regression Analysis (3.2.2) to understand what drives the cost of running the supply chain network. Last, the team utilized multiple graphs as part of the Visualization Analysis (3.2.3) to show Company A to capture the ideas of new findings or leads for further analysis.

3.2.1 Descriptive Analysis

To gain a better understanding of the data, we conducted statistical analysis on the supply, transfer, and demand locations, how much volume they processed, as well as the travel distance between each of them. Through the analysis, we found some wired routes. For example, Company A harvested the material in the US, shipped it to China for processing, then shipped it back to the US for final processing disregarding that they have some manufacturers in South America which could do the same job with lower traveling distance, potentially lower shipping cost.

Next, we ran the analysis against the shipping cost/kg and identified some outliers with extremely high unit shipping costs. Then we shared those findings with Company A and recommended that the company do an internal review to determine whether these outliers are justified and seek any opportunities to improve their supply chain.

3.2.2 Regression Analysis

We tried to identify the important cost drivers for logistics costs from the historical data to find the levers we should focus on. By identifying the important cost drivers such as distance or volume, we would be able to present recommendations that will be cost-efficient to have a positive impact on the operating profit of Company A's skincare business. We explored various features and performed regression analyses between shipping cost, shipping distance, and shipping volume, including running the regression with dummy variables to investigate possible relationships between certain regions and transportation modes.

Specifically, we performed the following analyses:

- Run regression between cost vs. adjusted SAP volume/distance by filtering a certain range of distribution cost/kg of 10, 100, 120, 130, and 150

- Run regression between cost/kg/km vs. adjusted SAP volume
- Run regression with dummy variables of different manufacturer regions between cost/kg/km vs. adjusted SAP volume
- Run regression between cost/kg/km vs. adjusted SAP volume by setting manufacturer region as US
- Run regression between cost/kg/km vs. adjusted SAP volume by setting SAP volume at a certain level of 20, 30, and 50

Unfortunately, as presented in the results section, these analyses did not yield any significant results. We believe that the format of data that was used to perform these analyses was a key cause for the lack of insights. During our research, we faced several challenges while gathering data from Company A. One major obstacle was the format of transactional data: rather than having access to each shipment (i.e., cost, shipment size, origin, destination, and cost), the data that was provided was aggregated yearly. As a result, we had to modify our objectives and pivot our approach to consider other factors that could impact the supply chain network design for natural botanical ingredients beyond cost.

3.2.3 Visualization Analysis

We used Power BI and Excel to visualize and analyze our supply chain network. Power BI was used to create maps, charts, and plots to visually display the volume distribution and relationships between distance, cost, and volume. Excel was used to graph the distribution of travel distances between the countries of origin to manufacturers and manufacturers to Company A Sites. These findings helped us identify outliers for further investigation by Company A and develop a network design optimization model.

3.3 Objective 2: Formulating Recommendations for redesigning the current supply chain network to decrease travel distances and reduce environmental impact

Based on the results of our literature review, the transshipment model is the most relevant approach to our problem. This model is commonly used in transportation and logistics to optimize the flow of goods across a supply chain network (Dondo et al., 2009)

To process data to be used in our model, we performed the following operations:

1. (1) Introduced location coordinates for different nodes of our network (see Section 3.3.1)
2. (2) Computed travel distances between different nodes of the network (see Section 3.3.2)

3.3.1 Introducing Location Coordinates for different Nodes

We use geographic coordinates (latitude and longitude) to represent the location of each node on the Earth's surface. Geographic coordinates are commonly used in applications such as transportation networks, where distances between nodes are calculated using geographic distance metrics, such as the Haversine formula, which we explain in section 3.3.2.1. Geographic coordinates can be used as input data to calculate distances, travel times, or other location-based parameters in the optimization model. In our project, we mainly used it to calculate distance. We used open sources to identify the following coordinates for each location.

Country of Origin
Biggest Port Location in the Country (The data was gathered from the World Shipping Council)

*Accurate location of Country of Origin was not given, so we had to set certain location for all the countries of origin

Manufacturer
Manufacturer Location
Closest Airport Location
Closest Port Location

Company A Site
Company A Site Location
Closest Airport Location
Closest Port Location

3.3.2 Computation of Travel Distances

It is required to consider multiple variables to assess Company A's current supply chain network and develop the optimal solution. We assumed traveling distance is one of the most critical factors. Company A has categorized its transportation modes into three options: truck, sea freight, and air freight. We developed three different ways of computing travel distances depending on the mode of transportation.

Truck transportation

If the material is shipped by truck, we used Euclidean distance to calculate the traveling distance times circuity factor of 1.2. This method is a straightforward and practical way to calculate the truck distance. To accurately calculate shipping distance between different locations, we used the Haversine package available in Python, which uses latitude and longitude to determine distances. To account for differences between the Euclidian and travel (i.e., real) distances, we multiplied the Euclidian distances by 1.2. This approach was applied by multiple papers. One of the examples is from Karou et al. (2014) which used 1.2 as a constant multiplier for calculating the estimated distance from the straight-line distance.

Sea transportation

For shipments using sea transportation, we followed the following steps:

Step 1: Identifying the closest port We first identified the closest port to the manufacturer and Company A's sites. This helped us determine the optimal route for the shipment and minimize travel distances.

Step 2: Computing travel distances in the network to compute the travel distances, we needed to consider multiple legs of transportation, as additional truck routes were needed to connect the different nodes in the network to ports. Therefore, we computed the distance in three parts:

(1) Distance by truck between the manufacturer and the port. (2) Distance by sea freight between the two ports. (3) Distance by truck between the port and the Company A site.

To compute distances (1) and (3), we used the same methodology as for truck routes. (Please refer to the previous paragraph for details on this methodology.) To compute the distance by sea route, we used the Searoute package in Python (Halili, 2009). This package considers the real shipping footprint and provides a significant increase in measurement accuracy compared to using the Haversine package. When a route was identified as "ship by boat", the traveling distance between two ports was calculated using the Searoute package.

For a visual illustration of our methodology for Sea shipments, please refer to Figure 5.

Figure 5 Sample of a Real Searoute Shipping between Hong Kong and London

Air transportation

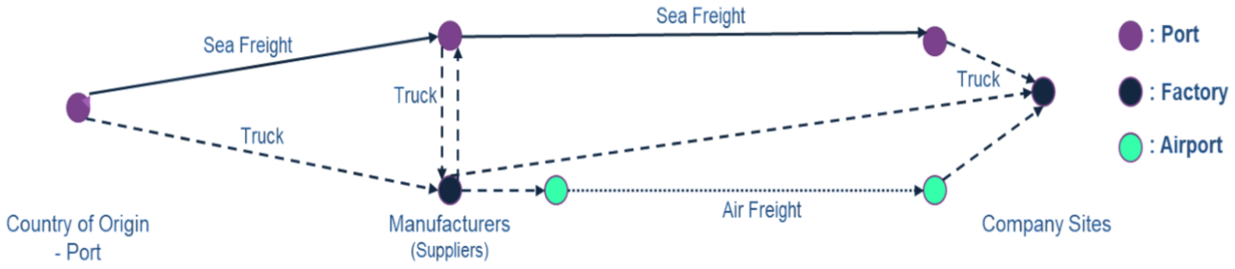
For air shipments, we followed a similar approach, but with the airport replacing the port as the location of interest.

To calculate the travel distances, we used the same methodology as for truck and sea routes (please see previous paragraphs for details). We identified the closest airport to the manufacturer and Company A's sites, and computed the distance in three parts:

(1) Distance by truck between the manufacturer and the airport. (2) Distance by air freight between the two airports. (3) Distance by truck between the airport and the Company A site.

For a visual illustration of our methodology for air shipments, please refer to Figure 6.

Figure 6 Distance Calculation Among Different Transportation modes



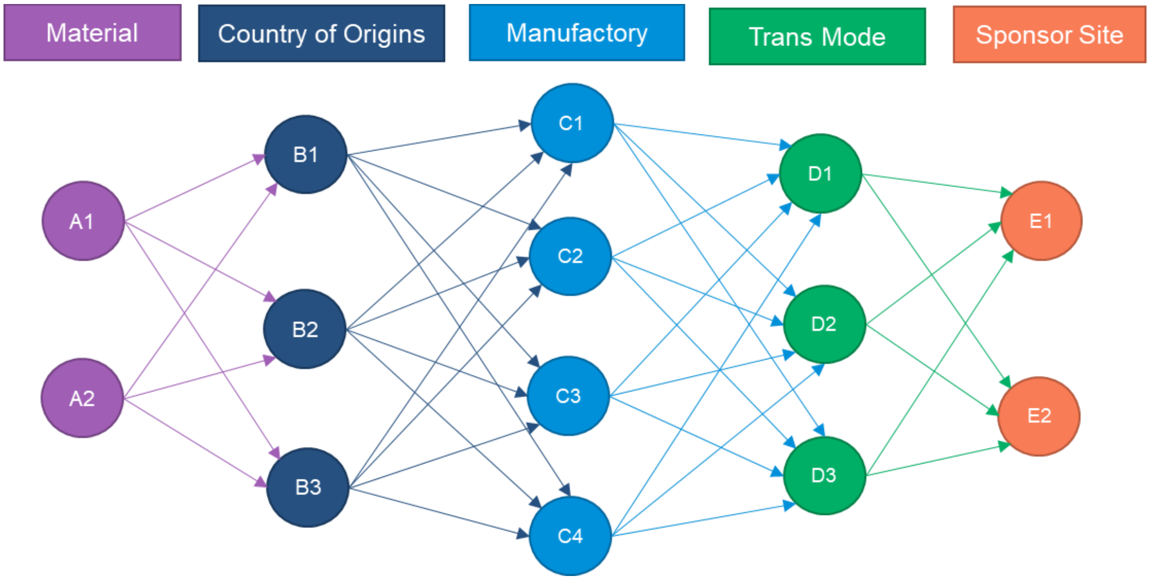
3.3.3 Optimization Model

We utilized the transshipment problem and expanded it with the following dimensions:

- Consideration of different transportation modes and mode-specific distances
- Consideration of multiple products

Figure 7 displays the network with all the parameters added.

Figure 7 Travel Structure Combinations: A Demonstration of All Possible Routes



3.3.3.1 Model Establishment

Our optimization model is based on the transshipment approach. We began by compiling a list of supplies, demands, distances between Country of Origin and Manufacturers, and distances between Manufacturers and Company A sites. To determine inbound flow, we established decision variables to represent the amount of shipment from each country of origin to each manufacturer, while outbound flow refers to the amount of shipment from each manufacturer to each Company A site. The objective function is set to minimize the product of the distance and the volume of travel. We have established constraints that limit inbound flow to be less than or equal to the supply, outbound flow to be greater than or equal to the demand, and inbound flow to equal outbound flow. We also imposed transportation modes constraints. If the country of origin and manufacturer are in the same continent and they are in Europe or North America, truck transportation modes are chosen, and boat transportation modes is chosen otherwise. Boat transportation modes are always chosen if the country of origin and manufacturer are not in the same continent. If the manufacturer and destination are in the same continent, the truck transportation modes are chosen, and if they are not in the same continent, the truck transportation modes is not chosen. Using this model, we ran our calculations and received the optimized solution.

3.3.3.2 Model Formulation

To formulate our optimization model, we first define different sets of our network. Let M be the set of botanical materials. Let O be the set of countries of origin locations. Let K be the set of manufacturer locations. Let T be the set of transportation modes. For each country of origin $\mathrm{o} \in \mathrm{O}$ and each material $\mathrm{m} \in \mathrm{M}$, we can define the supply s_{om}, which represents the volume supplied of material $\mathrm{m} \in \mathrm{M}$ from the country $\mathrm{o} \in \mathrm{O}$.

Let D be the set of destination locations. For every destination $then \in \mathrm{D}$ and each material $\mathrm{m} \in \mathrm{M}$, we can define the demand $\mathrm{d}_{\mathrm{dm},}$ which represents the demand of material m for the destination d.

For each country of origin $\mathrm{o} \in \mathrm{O}$, each manufacturer location $\mathrm{k} \in \mathrm{K}$, and each transportation modes $\mathrm{t} \in \mathrm{T}$, we can define the distance between the country of origin and manufacturer location as $\mathrm{y}_{\mathrm{okt}}$.

Similarly, for each manufacturer location $\mathrm{k} \in \mathrm{K}$, each destination $\mathrm{d} \in \mathrm{D}$, and each transportation modes $\mathrm{t} \in \mathrm{T}$, we can define the distance between manufacturer location and destination as $\mathrm{y}_{\mathrm{kdt}}$.

We consider the following decision variables:

- $\mathrm{f}_{\mathrm{okmt}}$, corresponding to the flow of the material $\mathrm{m} \in \mathrm{M}$ between the country of origin $\mathrm{o} \in \mathrm{O}$ and the manufacturer $\mathrm{k} \in \mathrm{K}$ by transportation modes $\mathrm{t} \in \mathrm{T}$

- f_{mkdt}, corresponding to the flow of the material $m \in M$ between the destination $d \in D$ and the manufacturer $k \in K$ by transportation modes $t \in T$

We base our model on the linear program by Pašagić (2003). The model can be formulated as follows:

$$\text{Min } f(x) = \sum y_{okt} * \sum f_{okmt} + \sum y_{kdt} * \sum f_{mkdt} \tag{1}$$

$$\sum_{k \in K} \sum_{t \in T} f_{okmt} \leq s_{om}, \forall o \in O, \forall m \in M \tag{2}$$

$$\sum_{k \in K} \sum_{t \in T} f_{mkdt} \geq d_{dm}, \forall d \in D, \forall m \in M \tag{3}$$

$$\sum_{d \in D} \sum f_{mkdt} = \sum_{o \in O} \sum f_{okmt}, \forall k \in K, \forall m \in M, \forall\, t \in T \tag{4}$$

$$f_{okmt} \geq 0, \forall o \in O, \forall k \in K, \forall\, m \in M, \forall t \in T \tag{5}$$

$$f_{mkdt} \geq 0, \forall d \in D, \forall k \in K, \forall\, m \in M, \forall t \in T \tag{6}$$

Equation (1) is the objective function of the model, which aims to minimize the inbound travelling distance and outbound traveling distance combined. Equation (2) represents model constraints to set the inbound flow always needs to be less or equal to the supply. Equation (3) represents model constraints to set the outbound flow always needs to be greater or equal to the demand. Equation (4) represents model constraints to set the inbound flow always needs to equal to the outbound flow as the transfer node, manufacturer location doesn't serve as the storing location. Equation (5) represents model constraints to set the inbound flow can't be negative. Equation (6) represents model constraints to set the outbound flow can't be negative.

In addition, we need to ensure that we are establishing feasible routes. For this purpose, we selectively introduce additional constraints:

The first set of constraints ensure that sea transportation cannot be used between the country of origin and a manufacturer if they are both located in Europe or North America:

$$f_{okm(sea)} = 0, \forall o \in O, \forall k \in K, \forall\ m \in M \tag{7}$$

The second set of constraints ensure that land transportation cannot be used between the country of origin and a manufacturer if they are not both located in Europ or North America:

$$f_{okm(land)} = 0, \forall o \in O, \forall k \in K, \forall\ m \in M \tag{8}$$

The third set of constraints ensure that land transportation cannot be used if a manufacturer and the destination are not located in the same continent:

$$f_{mkd(land)} = 0, \forall d \in D, \forall k \in K, \forall\ m \in M \tag{9}$$

The fourth set of constraints ensure that air transportation cannot be used if a manufacturer and the destination are located in the same continent:

$$f_{mkd(air)} = 0, \forall d \in D, \forall k \in K, \forall\ m \in M \tag{10}$$

The fifth set of constraints ensure that sea transportation cannot be used if a manufacturer and the destination are located in the same continent:

$$f_{mkd(sea)} = 0, \forall d \in D, \forall k \in K, \forall\ m \in M \tag{11}$$

3.3.3.3 Estimated CO_2 Emission Calculation

Company A has not applied state-of-art and cautious methodologies to calculate the CO_2 emissions from its procuring operations. Company A team is at a very early stage to understand its operation from the ESG-centric point of view. Therefore, we compared a few available services provided online such as EcoTransit, Carbon Footprint, and Myclimate, that estimate CO_2 emissions for logistics operations and finally reverse-engineered the methodologies to understand the basic concepts to calculate CO_2 emission. CO_2 emission from logistics is calculated with three factors: gross weight of transported goods, distance, and CO_2 emission multiplier given transport mode (Stojanovic et al, 2021). For our equation, we assumed that each transportation mode will have different linear equation with slopes and interceptor, and slope will be multiplied by the distance. At last, the output of the linear equation will be multiplied by the weight of the package. We did not consider route's specific factors such as road congestion, elevation gain and loss, makes and models of trucks, ship, and airplane, etc.

When calculating CO_2 emission of logistics operation, transportation methods equip different parameters, which work as an intercept and multiple for the formula, based on the different regulations around the world. Distance and volume are usually in linear relationship with a result, distance. We already possess all the necessary factors in our model to calculate estimated CO_{2f} emission for each material and each route they follow. These results were provided to Company A so that they can understand the social impact of their current operations and set a goal for the future.

3.3.3.4 Distance Calculation Validation

We picked six cities in our supply chain network and used them to check whether distance calculation feature in our model works well as expected. We tested all three transportation modes we considered in the model. As written in Figure 8 below, there was ~ 5.1% error when tested for truck shipment. It is usually difficult to have high accuracy for truck shipping distance because truck drivers can choose different routes in the road network upon any circumstances such as unexpected weather or road congestion.

Figure 8 Distance Validation Using the Optimization Model and Google Maps

Origin	Destination	Transportation modes	Distance from the model	Distance from Google maps (Straight Line)	Error
LA(US)	Nagoya (Japan)	Ship	9,443 km	9,047.38 km	395.62 km (4.3%)
Algeciras (Spain)	Fontenay-sur-Eure (France)	Truck	1,399 km	1,474.13 km	75.13 km (5.1%)
Knockrow (Australia)	Rio de Janeiro (Brazil)	Air	14,287 km	13,987.08 km	299.92 km (2.1%)

4 RESULTS

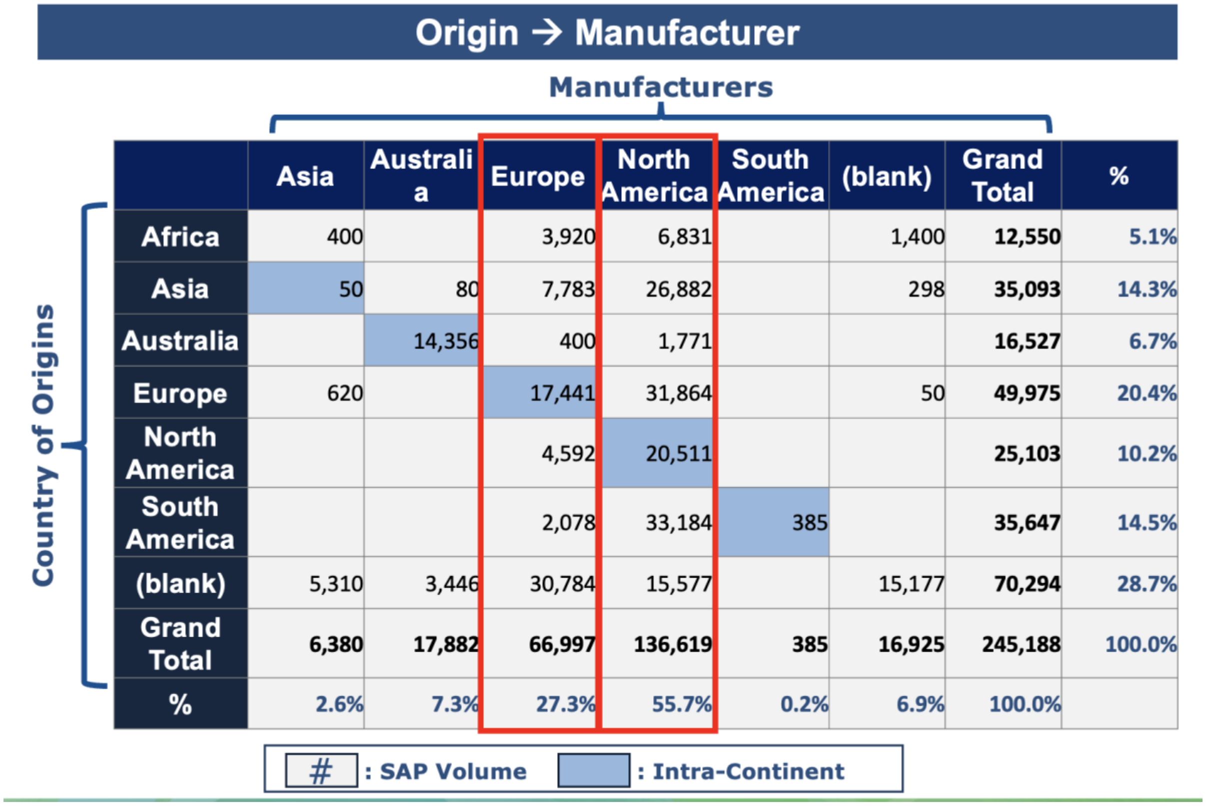
The key question for this project was to figure out the potential improvement that could be made to the current supply chain network. And then find how much improvement could be captured by selecting manufacturers in different regions to decrease the natural botanical ingredients' travel distance. In this chapter, the team presents the results from the regression analysis, the evaluation results for the current network and the results from the Optimization Model and check how efficient the supply chain network could become.

The first output of the analysis was the distribution of countries of origin with volume depicted with bubbles on the world map. As shown in Figure 9, various natural botanical ingredients are coming from many countries around the world.

Figure 9 Material Volume from Each Country of Origin

Second output is the volume flow. As shown in Figure 10 and 11, which display the current inbound and outbound flow from a continental perceptive.

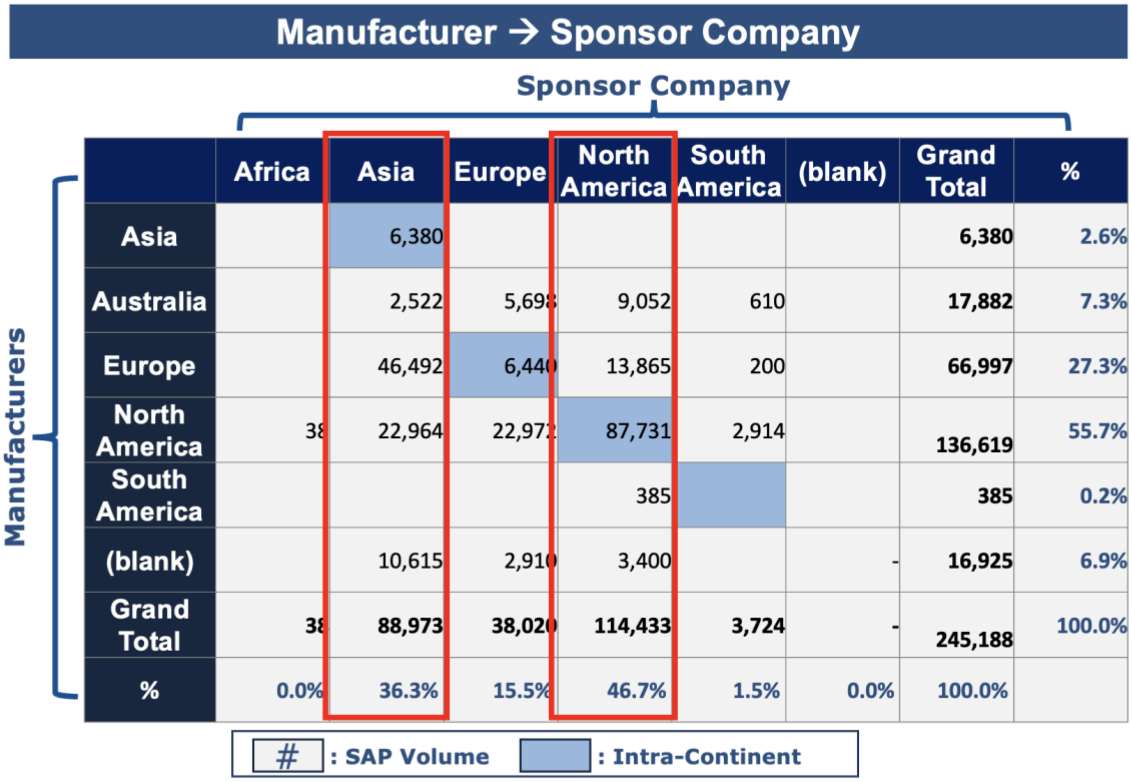
Figure 10 Country of Origin to Manufacturer: Volume by Continents



	Asia	Australia	Europe	North America	South America	(blank)	Grand Total	%
Africa	400		3,920	6,831		1,400	12,550	5.1%
Asia	50	80	7,783	26,882		298	35,093	14.3%
Australia		14,356	400	1,771			16,527	6.7%
Europe	620		17,441	31,864		50	49,975	20.4%
North America			4,592	20,511			25,103	10.2%
South America			2,078	33,184	385		35,647	14.5%
(blank)	5,310	3,446	30,784	15,577		15,177	70,294	28.7%
Grand Total	6,380	17,882	66,997	136,619	385	16,925	245,188	100.0%
%	2.6%	7.3%	27.3%	55.7%	0.2%	6.9%	100.0%	

: SAP Volume ▨ : Intra-Continent

Figure 11 Manufacturer to Company A: Volume by Continents



Manufacturer → Sponsor Company

Sponsor Company

Manufacturers

	Africa	Asia	Europe	North America	South America	(blank)	Grand Total	%
Asia		6,380					**6,380**	2.6%
Australia		2,522	5,69	9,052	610		**17,882**	7.3%
Europe		46,492	6,44	13,865	200		**66,997**	27.3%
North America	38	22,964	22,97	87,731	2,914		**136,619**	55.7%
South America				385			**385**	0.2%
(blank)		10,615	2,91	3,400		-	**16,925**	6.9%
Grand Total	**38**	**88,973**	**38,02**	**114,433**	**3,724**	**-**	**245,188**	100.0%
%	0.0%	36.3%	15.5%	46.7%	1.5%	0.0%	100.0%	

\# : SAP Volume ▨ : Intra-Continent

Third output is the relationship among three features: cost, volume, and distance. As shown in Figure 12 and 13, which displays scatterplots between unit shipping cost and travel distance/shipping volume. Armed with these findings, we then move to regression for further analysis.

Figure 12 Unit Shipping Cost Distribution per Shipping Volume by All Transportation Modes

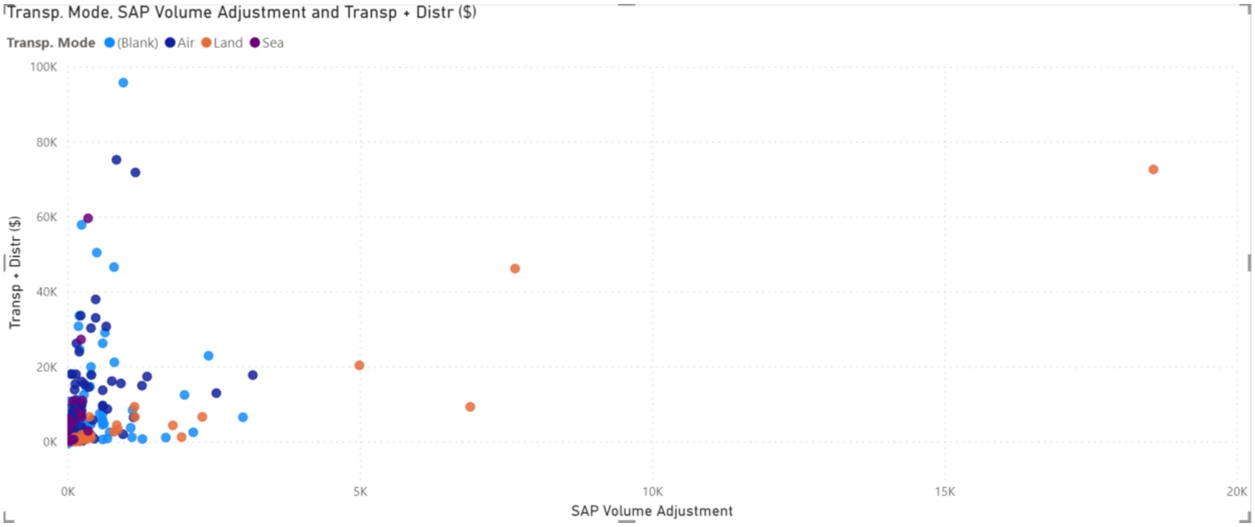
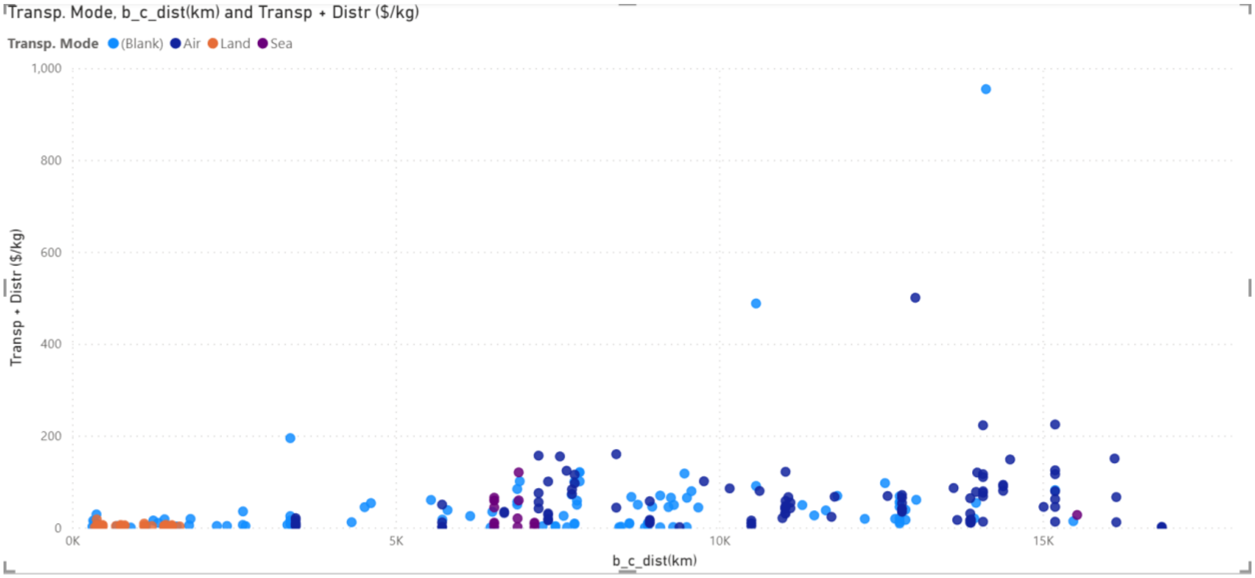


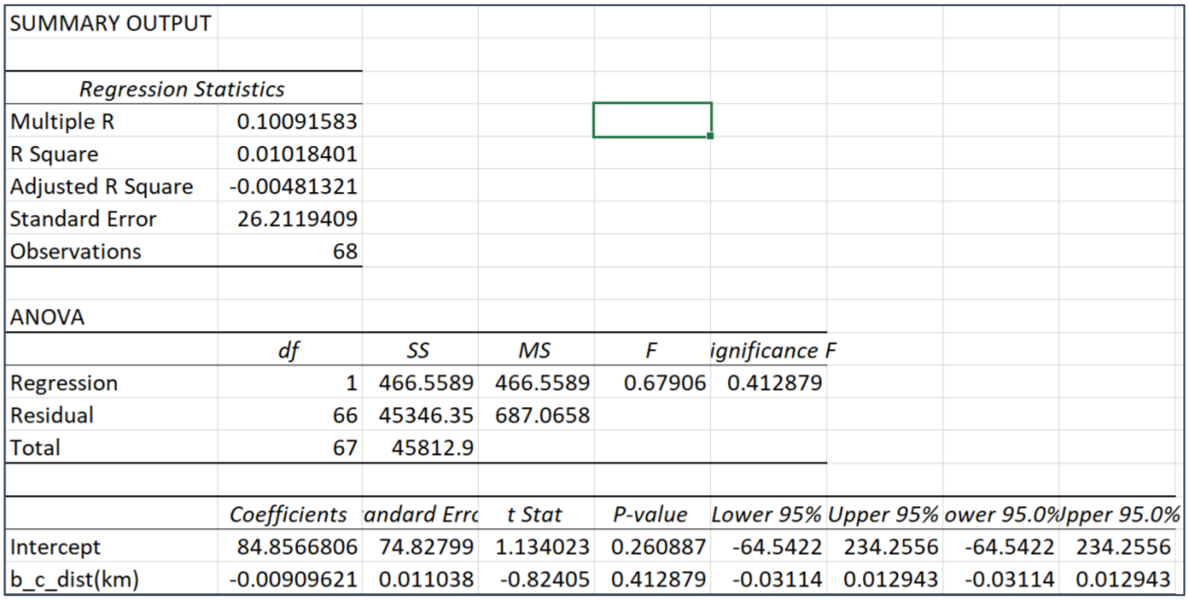
Figure 13 Unit Shipping Cost Distribution per Shipping distance (Manufacturer to Company A's Sites) by All Transportation Modes



We conducted multiple sets of regression analysis with different groups of data, picked from the original dataset. Figure 14, 15, and 16 show the regression statistics summary for 3 different scenarios. The below bullet points are the results we found during the regression analysis.

- R squared was less than 0.2 until I set the cost at $150/kg, I treat all routes above that as air-shipping (27 rows), which shows a strong correlation. However, the rest of the data still shows a very weak relationship.
- There is no strong relationship between each variable from global perspective
- There is no strong relationship between each variable from different manufacturer regions
- There is no strong relationship between each variable from the US manufacturer
- There is no strong relationship between each variable from different SAP Volume

Figure 14 Correlation between Distance and Cost from EU to USA



SUMMARY OUTPUT

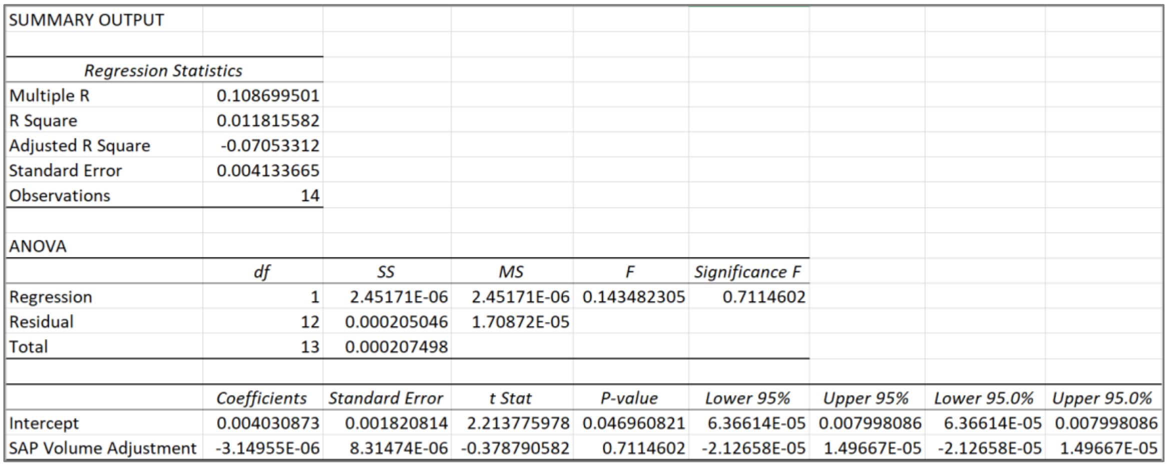
Regression Statistics	
Multiple R	0.10091583
R Square	0.01018401
Adjusted R Square	-0.00481321
Standard Error	26.2119409
Observations	68

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	1	466.5589	466.5589	0.67906	0.412879
Residual	66	45346.35	687.0658		
Total	67	45812.9			

	Coefficients	*andard Errc*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Jpper 95.0%*
Intercept	84.8566806	74.82799	1.134023	0.260887	-64.5422	234.2556	-64.5422	234.2556
b_c_dist(km)	-0.00909621	0.011038	-0.82405	0.412879	-0.03114	0.012943	-0.03114	0.012943

Figure 15 Correlation between Volume and Cost from France to the USA



SUMMARY OUTPUT

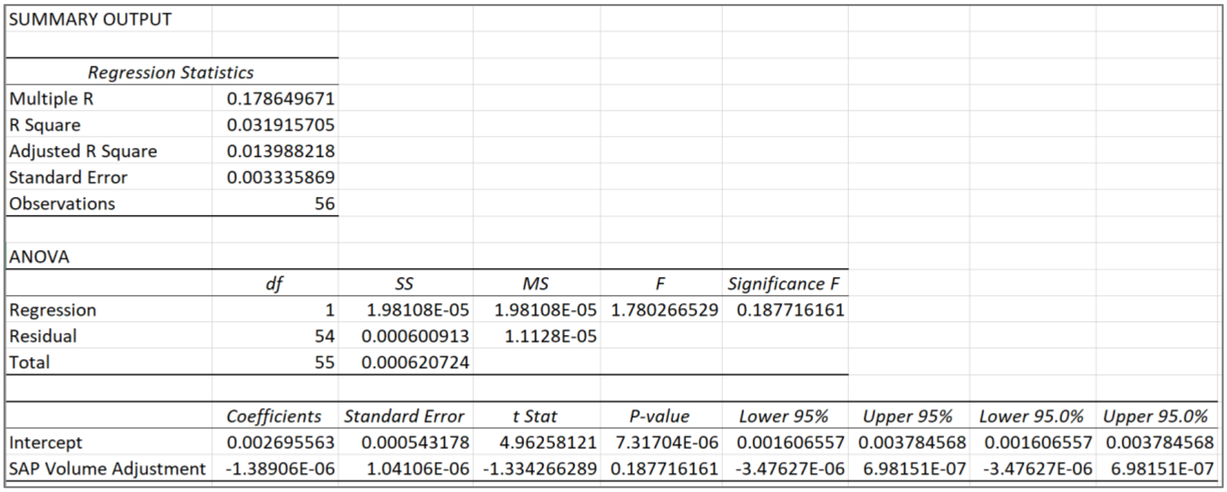
Regression Statistics	
Multiple R	0.108699501
R Square	0.011815582
Adjusted R Square	-0.07053312
Standard Error	0.004133665
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.45171E-06	2.45171E-06	0.143482305	0.7114602
Residual	12	0.000205046	1.70872E-05		
Total	13	0.000207498			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.004030873	0.001820814	2.213775978	0.046960821	6.36614E-05	0.007998086	6.36614E-05	0.007998086
SAP Volume Adjustment	-3.14955E-06	8.31474E-06	-0.378790582	0.7114602	-2.12658E-05	1.49667E-05	-2.12658E-05	1.49667E-05

Figure 16 Correlation between Volume and Cost from USA to USA with Singled-sourced material



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.178649671
R Square	0.031915705
Adjusted R Square	0.013988218
Standard Error	0.003335869
Observations	56

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.98108E-05	1.98108E-05	1.780266529	0.187716161
Residual	54	0.000600913	1.1128E-05		
Total	55	0.000620724			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.002695563	0.000543178	4.96258121	7.31704E-06	0.001606557	0.003784568	0.001606557	0.003784568
SAP Volume Adjustment	-1.38906E-06	1.04106E-06	-1.334266289	0.187716161	-3.47627E-06	6.98151E-07	-3.47627E-06	6.98151E-07

Unfortunately, our best-fitting model still had a very low statistical significance (adjusted R^2 of 0.0615). We formulate several possible explanations for this:

1. The dataset is from 2021-2022, the whole supply chain was disrupted due to Covid-19. The cost could be different from the normal time
2. Unable to identify transportation modes for each route, constantly putting data into a group where their shipping method is different

3. When cleaning the data (empty sell, negative value, separate adjusted sap volume into new rows), the size of the dataset keeps shrinking and evolving into different ratio

Initially, we aimed to minimize total shipping cost, but the regression analysis revealed no significant relationship between distance, cost, and volume. We shared our findings with Company A and offered possible explanations. Subsequently, we decided to drop the cost variable and modified our objective to minimize total shipping distance as the moving volume multiplied by total travel distance.

4.1 Results of the Assessment of the Current Supply Chain Network

The company’s current supply chain network has around 6.4 million kilometers (estimated) when all the routes’ distances are combined. The average distance is around 8,800 kilometers, while the longest distance is 22,890 kilometers. When we divide the total distance into two categories: inbound and outbound, the total sum of inbound distance is around 3.9 million kilometers, based on the key statistics of all route’s distances.

For inbound distances, China, as a country of origin, must send the botanical feedstock to manufacturers around the world taking up almost 23% of the inbound distance. For outbound, the manufacturer in the US has to send the (processed) natural botanical ingredients to many Company A manufacturing sites around the world. The distance natural botanical ingredients must travel from the US to Company A manufacturing sites take up more than 50% of the outbound travel distance. Based on the key statistics of the current supply chain network, we propose some strategic recommendations so the company can find more balance and build a more efficient supply chain network:

1. Company A should strengthen the relationships and build a stronger supplier base in the Asian region, especially in China, so that the inbound travel distance could decrease.

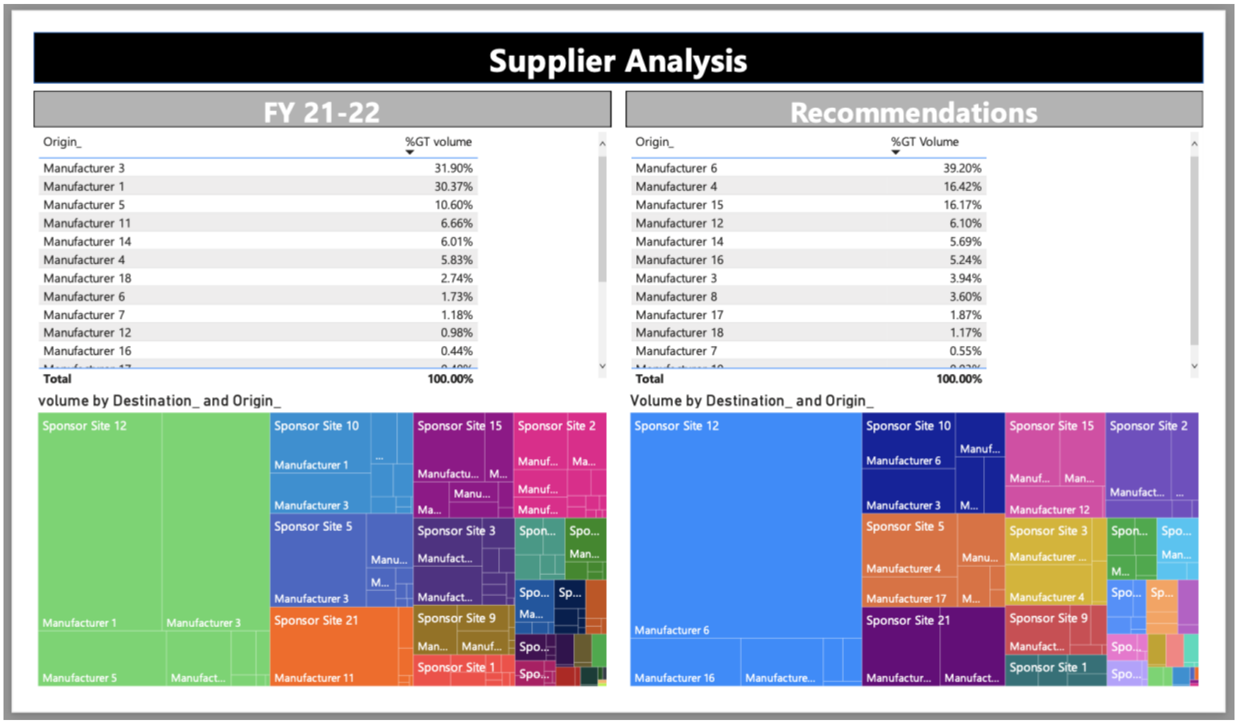
2. Company A should relieve the concentrated volume for the suppliers (manufacturers) in the US so that the (processed) natural botanical ingredients do not travel long distances. Therefore, Company A should find and build stronger supplier relationships in other regions than the US.

With recommendations above, it is obvious that Company A should keep its eyes on the Asian region to discover new suppliers or check whether available resources are ready from the current supplier list.

The strategic directions listed above become more inevitable when we consider the volume assigned to each country in addition. As of now, the manufacturers in the US must process over 70% of the natural botanical ingredients. The manufacturer in the Asian region is barely taking up any proportion of the operation while the demand in the region is relatively important and big enough to utilize suppliers with economies of scale. There are two points regarding this matter. First, any unexpected circumstances in the US region could impact the whole supply chain seriously. Congestion in the major ports, natural disasters, or increases in logistics fees are good examples.

When we take a closer look at the list of suppliers, over 60% of the botanical feedstock is processed in the US by two manufacturers, each making up around 30% equally. The third US supplier makes up over 70% of the total volume considered. The fourth supplier in terms of volume is also located in the US.

Figure 17 Supplier Analysis: Volume Distribution of Manufacturers and by Company A Sites


Supplier Analysis

FY 21-22

Origin_	%GT volume
Manufacturer 3	31.90%
Manufacturer 1	30.37%
Manufacturer 5	10.60%
Manufacturer 11	6.66%
Manufacturer 14	6.01%
Manufacturer 4	5.83%
Manufacturer 18	2.74%
Manufacturer 6	1.73%
Manufacturer 7	1.18%
Manufacturer 12	0.98%
Manufacturer 16	0.44%
Total	**100.00%**

volume by Destination_ and Origin_

Recommendations

Origin_	%GT Volume
Manufacturer 6	39.20%
Manufacturer 4	16.42%
Manufacturer 15	16.17%
Manufacturer 12	6.10%
Manufacturer 14	5.69%
Manufacturer 16	5.24%
Manufacturer 3	3.94%
Manufacturer 8	3.60%
Manufacturer 17	1.87%
Manufacturer 18	1.17%
Manufacturer 7	0.55%
Total	**100.00%**

Volume by Destination_ and Origin_

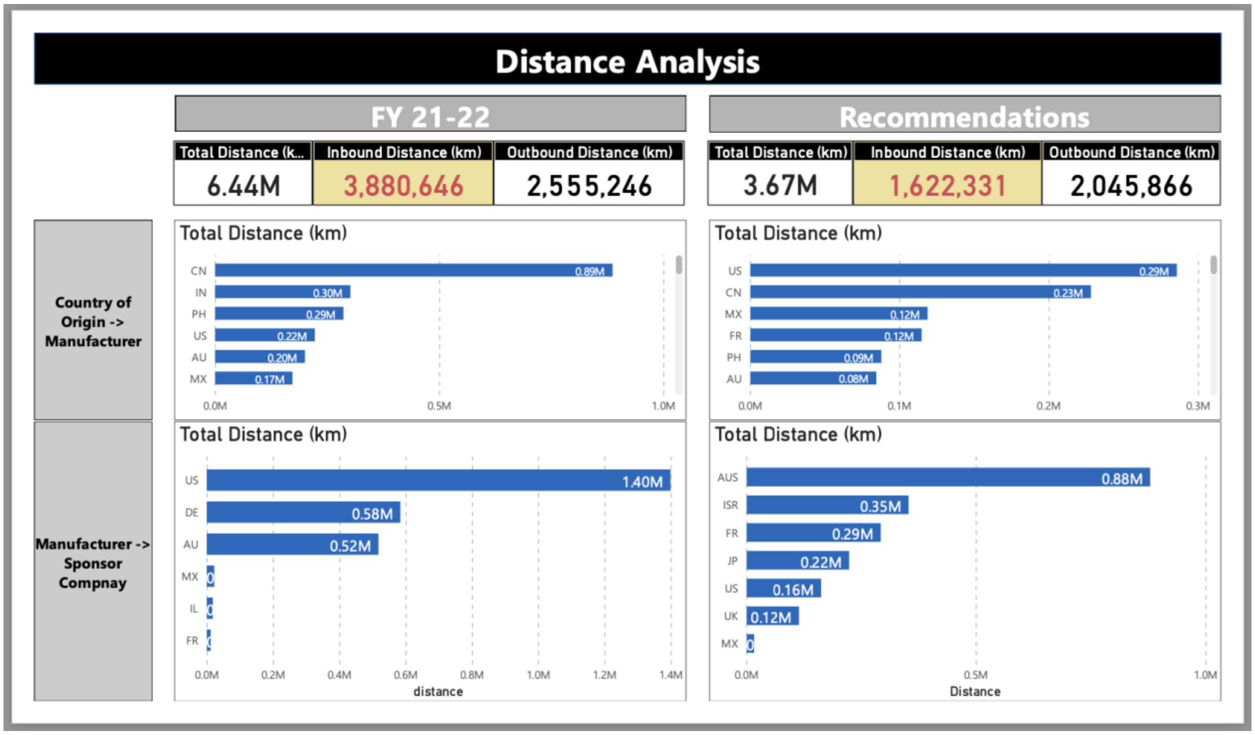
4.2 Results of the Optimization Model

According to the optimization model, which had an objective function to minimize the travel distance while meeting the same amount of demand from Company A's manufacturing sites, the total distance could be decreased to around 3.7 million kilometers from 6.4 million kilometers(estimated), which is around 43% improvement.

The approximate 2.7 million kilometers decrease can be broken into two parts: inbound and outbound. Inbound has a bigger impact on the change since 2.2 million kilometers come from the inbound. The current supply chain network should find more active suppliers closer to the countries of origin so that the botanical feedstock with more volume and weight could travel less distance at lower cost.

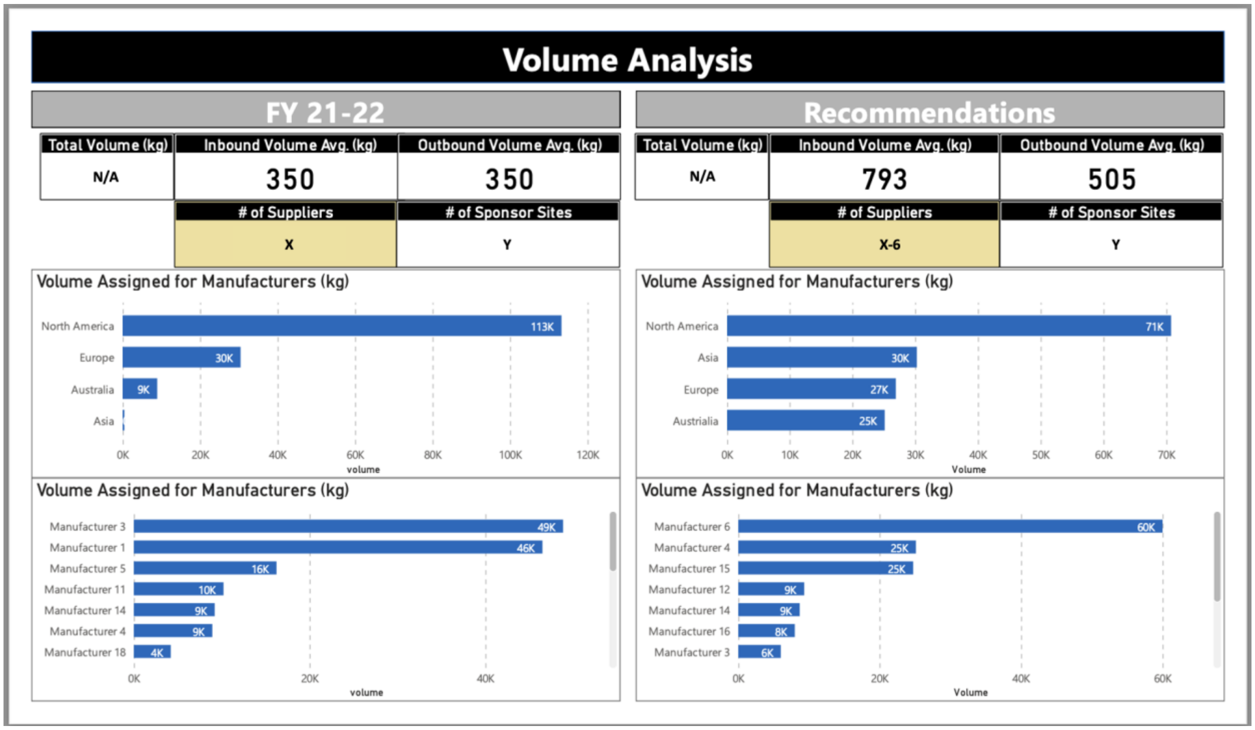
According to our analysis, China was the country of origin that had to send the botanical feedstock to many suppliers in various countries. Total inbound travel distance was around 3.8 million kilometers, and China was responsible for 0.9 million kilometers, making up almost 25% of it. On the other hand, other countries such as US and Mexico had suppliers close enough to process the botanical feedstock nearby. For outbound, as mentioned in the previous paragraph, the US was responsible for more than half of the outbound travel distance, sending processed natural botanical ingredients to Company A’s manufacturing sites near the consumer market. With recommended results in Figure 18, the model relieved the dependency on the US and now utilized Australia, Israel, France, and Japan to take on more workload of processing the natural botanical ingredients.

Figure 18 Distance Analysis: Total Travel Distance for Materials from Each Country



In terms of volume distribution of the supply chain network, the optimization model recommended reducing the number of suppliers to 12, dispersed in seven countries, from 18 suppliers in nine countries. The distribution of the volume to each region, not only North America but also Asia, Europe, and Australia has increased. The results perfectly align with the results of the distance analysis, previously stated, in the sense that the supply chain network is now recommended to relieve the concentration of the suppliers in the US.

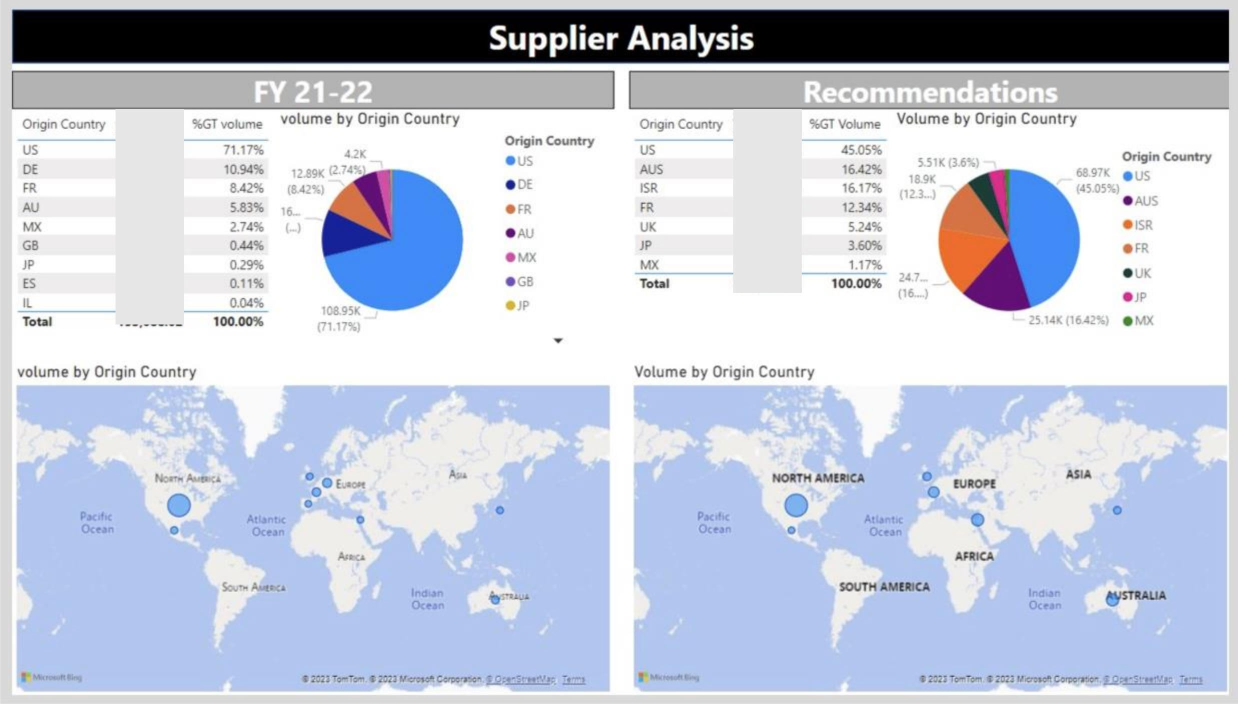
Figure 19 Volume Analysis: Volume Distribution for Each Continent and Manufacturer



The model is not just recommending assigning the volume, given demand, to different regions. The model is recommending putting the volume into different suppliers more evenly. The previous supply chain network had two suppliers that made up more than 62% of the total volume. Now the top two suppliers make up around 55%, and suppliers in Europe are responsible for more volume. At the same time, the model recommends getting rid of three suppliers that had only a few hundred kilograms to process, thus streamlining the supply chain network. The team assumes that Company A would have more controllability by aggregating the volume of natural botanical ingredients to fewer suppliers.

One of the key results to focus on is that the model recommends strengthening the supplier operation in the Asian region to process the natural botanical ingredients from China or to supply more volume to Company A’s manufacturing sites in the Asian region.

Figure 20 Supplier Analysis: Supplier Distribution of Countries in Terms of Volume



Supplier Analysis

FY 21-22

Origin Country	[redacted]	%GT volume
US	[redacted]	71.17%
DE	[redacted]	10.94%
FR	[redacted]	8.42%
AU	[redacted]	5.83%
MX	[redacted]	2.74%
GB	[redacted]	0.44%
JP	[redacted]	0.29%
ES	[redacted]	0.11%
IL	[redacted]	0.04%
Total	[redacted]	**100.00%**

Recommendations

Origin Country	[redacted]	%GT Volume
US	[redacted]	45.05%
AUS	[redacted]	16.42%
ISR	[redacted]	16.17%
FR	[redacted]	12.34%
UK	[redacted]	5.24%
JP	[redacted]	3.60%
MX	[redacted]	1.17%
Total	[redacted]	**100.00%**

5 CONCLUSION

5.1 The Results of Travel Distance Optimization Model

With the Optimization Model, we could identify the opportunities with quantitative back-ups that would provide clear strategic directions to improve the supply chain network in the long run. The Optimization Model now enables the team to additionally consider distance, one of the important drivers for logistics cost and CO_2 emission, therefore finding ways to improve the efficiency of the supply chain network for natural botanical ingredients.

We could address the two objectives we had at the early stage with the functions, calculating the distance between two nodes in the supply chain network and deriving the best locations for the supplier to have the least travel distance, enabled by Python.

- Objective 1: Assessment of the Current Supply Chain Network to provide visibility on the current network performance and identify key areas for improvement
- Objective 2: Formulating Recommendations for redesigning the current supply chain network to decrease travel distances and reduce environmental impact

In addition, we also provided a handbook for Company A so that they can utilize the optimization model with new datasets in the future. It covers the basic steps to run the optimization model and how to change the values for input so that Company A can try different scenarios.

5.2 Future Recommendations for the Optimization Model

The Optimization Model was intended to have more flexibility for future uses, especially for the Company A team with limited experience with Python. So, the model has its base layer of all the possible factors that could be considered, and additional constraints will be imported to shape the model to provide its solution.

An optimization model has always been considered a deterministic model. However, deterministic supply chain network design models do not take responsiveness and resilience into consideration, and most stochastic models take them into account only partially (Klibi et al., 2010). Although static deterministic supply chain network design models can often be solved with modern commercial solvers, this is far from being true for realistic multi-period stochastic models. Very few efficient heuristic methods have been developed to solve these models and this is another promising research direction. (Klibi et al., 2010) While constructing the model, we had to make certain assumptions due to the unavailability of certain data from Company A. However, each of these assumptions may introduce a level of inaccuracy to the result. It is important to acknowledge these limitations and potential sources of error. It is crucial to recognize that any model is an abstraction of reality, and the results should be interpreted in the context of the assumptions made and the limitations of the model. Ultimately, it is essential to continually gather and incorporate new data into the model to improve its accuracy and relevance over time.

Despite the challenge of unreliable models and results caused by the lack of accurate data, advancements in technology offer potential solutions. Staying up to date with emerging technologies and trends in the field of supply chain management is crucial for designing and operating efficient supply chain networks.

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