Supply Chain Network Optimization: Low Volume Industrial Chemical Product

by

Fred Dacha
B.S. Chemical Engineering, Virginia Commonwealth University 2003
M.B.A Smith School of Business, University of Maryland 2012

and

Li Jin
B.A. International Trade & Economics, Shanghai International Studies University 1996
M.B.A Oklahoma State University, 2003

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Signature of Author..
Master of Engineering in Logistics Program, Engineering Systems Division
May 23, 2012

Signature of Author..
Master of Engineering in Logistics Program, Engineering Systems Division
May 23, 2012

Certified by...
Dr. Tony Craig
Postdoctoral Associate, MIT Center for Transportation & Logistics

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

TABLE OF CONTENTS

ABSTRACT 4

ACKNOWLEGEMENT 5

1. INTRODUCTION 6

1.1 Economic Growth in South(Latin) America 7

1.2 TopChem Inc. and SKU-1 Solvent 7-8

1.3 TopChem Inc.SKU-1 Supply Chain 8-12

2. LITERATURE REVIEW 12-13

2.1 Chemical Industry Overview 13

2.1.1 Chemical Industry Volatility 13

2.1.2 Business Challenges in Chemical Industry 14

2.1.3 Feedstock and Cost Competitiveness 14-15

2.1.4 Global Demand for Chemicals 15

2.1.5 Transporation in Chemical Industry 15-18

2.1.6 Terminal Service Requirements 19

2.2 Supply Chain Network Models 19

2.2.1 Network Model Application 20

2.2.2 Network Optimization Problems 20-21

2.2.3 Supply Chain Network Designs 21-23

2.2.4 Scenario Analysis 23

3. METHODOLOGY 23

3.1 Traditional Transhipment Model 24

3.2 TopChem Inc.SKU-1 Supply Chain Network Model 24

3.2.1Model Parameters 24-25

3.2.2 Objective Function 25

3.2.3 Constraints 25

3.2.4 Total C2S and Extra Berth Cost 26

3.3 Excel Solver for Optimization Solution 26

3.4 Scenario Analysis 27

4. DATA ANALYSIS 27

4.1 Model Input 27

4.1.1 Supply Capacity and Costs 28
4.1.2 Terminal Capacity and Costs 28-30
4.1.3 Customers' Demand 31-32
4.1.4 Transportation Costs 33-35
4.1.5 Railcar Cost 35-36
4.1.6 Transportation Costs for Pickup Customers 37
4.2 Scenario Setup 37-38
5. RESULTS AND DISCUSSION 38
  5.1 Total Cost to Serve 38
  5.2 Cost Driver Analysis 39-44
  5.3 Product Flows Analysis 44-47
  5.4 C2S By Customers 47-52
  5.5 South America C2S With Increased Demand 52-53
6. CONCLUSION 53-56
7 MODEL LIMITATION AND FUTURE WORK 56
  7.1 Model Limitations 56
  7.2 Assumptions 57
  7.3 Transportation Lead-time and Variance 57
  7.4 Demand Variability 58
  7.5 Terminal Capacity and Inventory Level 58
  7.6 Future Work 58-59
REFERENCES 60-62

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Abstract

The chemical industry is a highly competitive and low margin industry. Chemical transportation faces stringent safety regulations meaning that Cost-To-Serve (C2S), costs associated with products net flow from manufacturers to customers, consists of a big percentage of the delivered product cost. Supply chain practitioners in this industry need to make key logistics decisions to minimize C2S for profitability and business sustainability. In this thesis, we present a network optimization model to minimize the total C2S for SKU-1, a low volume and low margin industrial chemical with a customer base spread across North and South America. We use a mathematical linear program to investigate the effects on total C2S when available production capacities and sources are shifted. We develop the model as a minimum cost flow problem, and more specifically, as a production and transportation problem (PTP). We analyze the total C2S under three scenarios. In the baseline scenario there are three manufacturing facilities in the Midwest, South East, and Europe. In the second scenario, where the Midwest supplier is excluded from the network, the C2S increases by 3%. In the third scenario, where both the Midwest and South East facilities are excluded, the C2S increases by 13%. Under each scenario we calculate the C2S for each individual customer and identify the customers most impacted by the change in supply. Our results provide insight regarding the changes expected to the supply network under capacity constraints and how those changes may affect the profitability of individual customers.

Thesis Supervisor: Tony Craig

Title: Postdoctoral Associate, MIT Center for Transportation & Logistics

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[1] The company and names of individuals have been withheld to protect confidentiality.

Introduction

Chemical companies are often concerned with minimizing their operational costs. Supply chain costs represent an average of 8-10% of sales revenue for chemical companies (Cefic 2004). They represent 37% of net value added in the chemical industry, a figure significantly higher than in other industries. For example, the figure is 18%, 26%, 28% and 30% for metal products, building materials, automobiles and paper products, respectively. This reflects the relatively low product value and high costs of moving and storing chemical products, given their bulky and hazardous nature (Braithwaite, A. 2002).

These costs are especially challenging to manage if a company serves geographically dispersed customers. The shift in robust economic activity away from developed economies in Europe and North America to emerging economies such as Brazil in South America and China in Asia has exacerbated that challenge. Following the recent U.S. recession and EU debt crisis, economic activities in the "West" have been flat at best. The United States economy weakened notably during 2012 and growth prospects for 2013 and 2014 remain sluggish (United Nations, 2012). While the effects of economic downturn have been felt across the world, countries in Asia and South America have continued to post impressive growth numbers. For example, between 2008 and 2012, East Asia and Pacific's annual GDP growth rates were at 8.48%, 7.46%, 9.69% and 8.13%. Latin America grew at 4.28%, -1.63%, 6.24% and 4.67%. In the same period, the U.S growth rates were -0.4%, -3.5%, 3.0% and 1.7%, while the EU's were 0.3%, -4.4%, 2.1% and 1.5%. (Trade Economics 2013)

1.1. Economic Growth in South (Latin) America

Latin America has maintained high levels of economic growth and financial resilience, attracting increased foreign investment and tourism, progressing towards poverty alleviation, and building a larger and more demanding middle class (World Economic Forum, 2013). Argentina, for example, had a GDP growth of 9.2% in 2010, 8.9% in 2011 and 2.6% in 2012 (Index Mundi, 2013).

Argentina has been diversifying its industrial base and experiencing a record growth in the automobile, textile and power sectors (Trading Economics, 2012). With a growing industrial economy and a population with an increased appetite for spending, demand for chemicals used in industrial operations or consumer goods has increased. This demand increase has prompted TopChem Inc.[2] to evaluate its global supply operations for SKU-1, and examine its selling strategies in both its existing markets and the growing economies.

1.2. TopChem Inc. and SKU-1 Solvent

TopChem Inc., a subsidiary of Top Inc., engages in manufacturing, marketing, sales and R&D of a full range of Petrochemical products around the world. The company was ranked in Chemical Week's billion dollar club (Chemical Week 2012) and in ICIS's top 100 chemical companies in 2012 (ICIS Top 100 Chemical Companies 2012). One of the products TopChem Inc. sells is a solvent called SKU-1. A Solvent is a substance that dissolves other substances to form a solution or separate different substances. SKU-1, is used in industrial and professional applications such as manufacturing process solvent, metal working, and coating. It is a hydrocarbon sourced from

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[2] The company and product name have been changed to protect confidentiality.

oil refineries producing anything from gasoline to jet fuel. SKU-1 competes for production capacity with other solvents and petrochemicals based on margin, volume and strategic importance. Given the economics of petrochemicals, which favors the production of higher margin products from available feedstock, any shift to higher cost supply locations and lengthened supply lines has the potential to significantly increase costs and make the SKU-1 business unprofitable.

1.3. TopChem Inc. SKU-1 Supply Chain

SKU-1 is distributed from refineries to end customers in North and South America in one of three ways: direct delivery to customers from refineries, delivery to customers through storage terminals and customer pickup from refineries or terminals. Manufacturing capacity is available in Europe and North America but not in South America. Figure 1.3a gives an overview of the global supply chain of SKU-1.

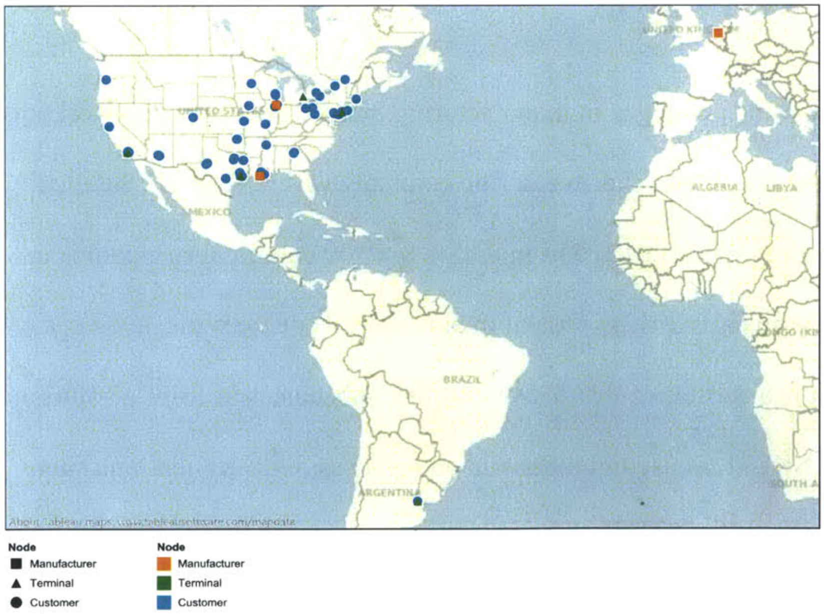


Figure 1-3a SKU-1 Global Supply Chain

Until recently, two North American refineries, one in South East and the other in Midwest, could be contracted to supply up to 11000 metric tons (MT) of SKU-1 each, sufficient to meet the demand of 7576 MT in North America and 2858 MT in South America. Figure 1-3b shows the most recent supply chain network.

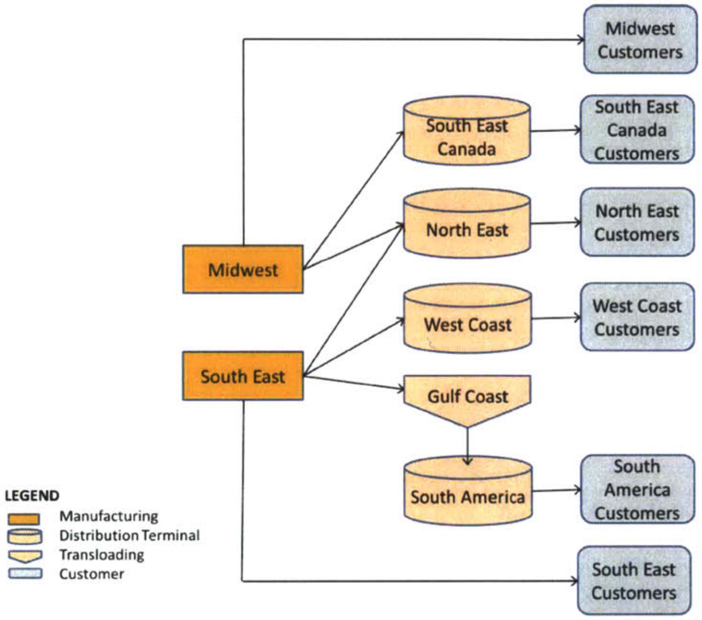


Figure 1-3b Most Recent SKU-1 Supply Chain

In the most recent supply chain structure, TopChem Inc. ships SKU-1 directly from refineries to terminals in North America by rail and to customers either by rail or road truck. For shipments to South America, TopChem Inc. uses rail transportation from the refinery to Gulf Coast and ocean freight from Gulf Coast to South America in a practice called "transloading". Transloading is the transfer of a shipment from one mode of transportation to another. The term is used when one form of transportation cannot be used for the entire trip (Carbis Fluid Handling, 2012). Currently, TopChem Inc. does not have a terminal in Gulf Coast.

TopChem Inc. expects demand in North America to remain flat and to double in South America in the next few years. However, the Midwest supply relationship has been discontinued and all supply now comes from the South East production facility. Given the potential supply constraints going forward, especially with increased demand in South America, TopChem Inc. has the opportunity to supplement from or completely shift supply to Europe. Also, TopChem Inc. will have terminal capacity in the Gulf Coast, which it does not have in the most recent supply network, dedicated to SKU-1. Figure 1-3c shows this possible future supply chain. In implementing this future supply chain, it is important to minimize cost-to-serve customers in order for the business to remain profitable.

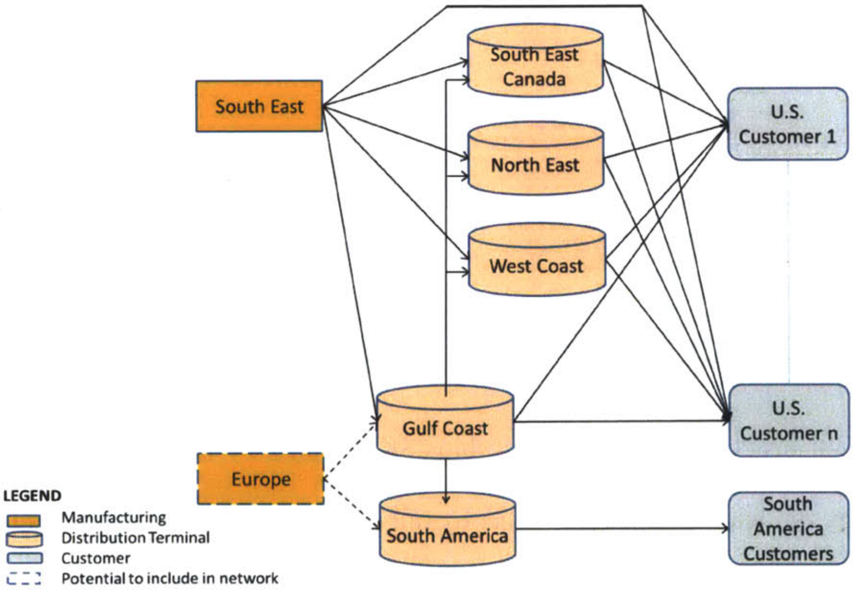


Figure 1-3c Future SKU-1 Supply Chain

The company is evaluating how to cost-effectively bring in global supply to meet global demand at the premise that its supply constraints are satisfied. Specifically, cost effectiveness is gauged by cost-to-serve (C2S), which is composed of manufacturing cost, transportation cost, railcar cost, berth cost, terminal cost, and inventory holding cost. These costs, stated in dollars per metric ton, are explained below:

- Manufacturing cost is the cost of production at the refineries when converting feedstock into SKU-1.
- Transportation cost is the cost of moving SKU-1 from its production facilities (refineries) to the end customers, including from production facilities to terminals (stock movement costs) and from terminals to the end customers. The appropriate cost is dependent on the mode of transportation - rail, truck, water and pipeline. All transportation handled by TopChem Inc. incurs a cost that is transferred to its customers. Customers who pick up their orders at either terminals or manufacturing facilities are not charged a delivery cost by TopChem Inc. because the customers cover the transportation cost by themselves.
- Railcar cost is the cost to rent a rail car when SKU-1 is shipped by rail to terminals or to customers.
- Berth cost is the port cost incurred when a ship, on its way to deliver different products to another port, for example South East, makes an extra stop in Gulf Coast to deliver SKU-1 from Europe. The cost is $18,500 per shipment and the current typical shipment quantity is 2600 MT. The optimization model determines the quantity to be shipped from Europe to the Gulf Coast terminal then the berth cost is calculated outside of the optimization model. When applicable, this cost is then allocates to all products leaving the Gulf Coast terminal for customers or for other terminals.
- Terminal cost is the product handling cost at terminals. The cost includes fixed and variable storage costs.

- Inventory holding cost is the cost the company incurs to store SKU-1 while servicing customers. The cost is incurred until product is transferred to customers.

Given the current supply situation and projected increase in demand for SKU-1, TopChem Inc. is interested in determining how the overall C2S and C2S for individual customers changes if SKU-1 is sourced from the South East and/or from the Europe. To answer this question, we develop a network optimization model, analyze various cost drivers in C2S, and present the changes in C2S for the whole network and by individual customers. The remainder of this paper is organized as follows. In the literature review section, we expound on the global shift and dynamics of economic growth, supply chain network optimization in relation to the chemical industry, interviews with chemical supply chain specialists, and previous studies on these topics. We then describe in detail the supply and demand of the low volume chemical products as well as the resulting transportation and storage challenges. In the methodology section, we detail how our network model is built and explain each cost component of C2S, and the logistics data that the TopChem Inc. provides. We then define and explain multiple scenarios that we evaluate. In the results and discussion section, we provide detailed analysis we draw from our model and associated business implications for the company. We perform scenario analyses showing the change in total C2S under different product supply conditions. Lastly, we lay out model limitations and future work for SKU-1not covered in this paper.

2. Literature Review

The distribution challenge presented by TopChem Inc.'s SKU-1 is a classic network optimization problem where competing factors and/or constraints dictate the optimal distribution strategy. By and large, the user needs to define the desired objective that the model aims to achieve. While objectives can range from meeting required customer service levels to maximizing revenue, most models aim to minimize total distribution costs. The literature available for this topic is extensive as it has been one of the oldest topics of interest in supply chain field. To that end, we focused our efforts on studying newer content of network optimization as well as evaluating the solvent supply chain and the challenges of marine transportation for chemical products. In this review, we document our findings and relate such findings to developing a distribution network model for TopChem Inc.SKU-1.

2.1. Chemical Industry Overview

TopChem Inc.SKU-1 is a solvent with multiple applications both in industrial and consumer products. As a chemical product, it shares certain attributes unique in the chemical industry that deserve a close examination.

2.1.1. Chemical Industry Volatility

The overall chemical industry is a highly volatile industry. There are multiple factors driving the market volatility, including market, technical and facility parameters. Market parameters include product demands, and feed stock availability and prices. Technical parameters include product yields, product qualities, and processing times/rates. Facilities parameters include facility reliability and availability. All these parameters have significant stochastic components. (Pekny and Reklaitis 2000) History shows tight supply resulted in increased prices and profit margins and would be followed by periods of substantial capacity addition, resulting in oversupply and declining prices and profit margins. In addition, chemical products are highly dependent on other sectors that are particularly cyclical, such as the building and construction, paper and pulp, and automotive, adding volatility nature of the industry. (GGC 10-Q file May 2009)

2.1.2. Business Challenges in Chemical Industry

Rising raw material costs, regulatory issues, and vertical integration from bulk to specialty chemicals have created the need for complex supply chains. Chemical producers have expanded their product portfolios to drive new revenue sources and higher margins, necessitating the creation of new markets and customer specific requirements to stay competitive. Business responsiveness becomes paramount in this customer-focused culture, putting pressure on chemicals producers to overcome the barriers to agility to improve profitability and continue to meet customer needs. (Rokohl 2012) In the TopChem Inc.SKU-1 business case, demand growth has shifted from developed markets to emerging markets. Its current supply base is shrinking, forcing the company to bring in new supply from distant market. These market dynamics, together with the fact that a lot of chemical business is driven by annual or multiyear contracts, pose strategic challenges that need to be addressed.

2.1.3. Feed-stock and Cost-Competitiveness

A refinery feedstock is product or a combination of products derived from crude oil and destined for further processing other than blending in the refining industry. It is transformed into one or more components and/or finished products (OECD, 2002). Petroleum naphtha is an intermediate hydrocarbon liquid stream derived from the refining of petroleum crude oil (J.H. Gary and G.E. Handwerk, 1984) that is further processed into high octane gasoline, solvents such as SKU-1 and other petrochemicals. Naphtha will remain the main feedstock for petrochemical production since the feed provides the greatest versatility as a feedstock and supply is expected to continue to be available from refineries operated to produce transportation fuels. (Nexant 2011) The petrochemical industry continues to be highly cyclical and commoditized. Therefore, finding ways to optimize production and minimize cost is important for success. The ability to use alternative feedstock is one of the key elements in achieving the lowest cost of production, especially in an environment where feedstock prices have become highly volatile.

2.1.4. Global Demand for Chemicals

Demand for chemical products will continue to grow, presenting supply chain challenges to this capacity-constrained and asset-intensive industry. The global demand for petrochemical products will keep a 4.4 percent growth rate before 2020, doubling global GDP growth rate. Demand surges in high-growth economies and capacity expansions in low-cost production areas will accelerate global trade in petrochemical products. Global Petrochemical products profit will reach its peak from 2015 to 2017. (Adams 2012)

Adams further predicts that, by 2020, global demand for chemicals will reach from 680 million tons to 1 billion tons, of which nearly 200 million tons to balance between supply and demand will be achieved by international trade. (Adams 2012)

Global chemical output grew to $4.12 trillion in 2010. It is forecasted that global chemical sales will grow about 3% per year to 2050. (Massey and Jacobs 2012) However as chemical production, trade, use and disposal continue to expand worldwide, this expansion is not evenly distributed geographically.

2.1.5. Transportation in Chemical Industry

Transportation in the chemical industry is done by different modes, namely, truck, marine, rail and pipeline modes among others. In the U.S., truck transportation accounted for 54% of the total transportation volume and 68% of the total spend in 2011. Truck transportation was followed by rail at 23% and 20%, respectively. Water took the third place with 20% and 8%, respectively and pipeline made up 3% of the volume and 4% of the spend. (Railroads and Chemicals 2012)

Long-distance, international transportation of liquid chemicals is conducted using one of five modes: pipeline, bulk tankers, parcel tankers, tank containers, or drums. Pipeline and bulk tankers are used primarily in the petrochemical industry for the transport of large quantities of a single product. Parcel tankers are smaller vessels with up to 42 tank compartments and are used to simultaneously transport multiple cargoes. Tank containers, also referred, to as ISO tanks, are designed for intermodal transportation by road, rail, and ship. (Erera, Morales, Savelsbergh, 2005)

In regard to storage, once produced, chemicals are stored in tank farms in the production facility to be transferred to a holding container used to transport the product. The use of such containers varies depending on product hazard, weight and transportation distance. The types of containers range from small drums to large parcel tankers that hold liquid products in separate bulk compartments in a ship.

Most large chemical companies use just about every means of transportation available and product is moved to and from multiple points. For example, DuPont, one of the largest chemical companies in the world, spends at least $1.6 billion a year on transportation and storage from 400 shipping points worldwide. The company uses intermediate bulk containers (IBCs), tank trucks, tank containers (ISO-tanks), rail tank cars, barges, and parcel tankers to move its chemical products. Such complexity is driven by company overall strategy and competition in the market that is often characterized by commodity products with tight margins, unique storage and handling requirements as well as demand and regulatory variations by customers and geographic regions. (Donelly, J. 2000)

Performance of transportation companies often forms a significant decision factor in determining transportation rates and service level variability. To optimize chemical transportation, companies have to evaluate the pros and cons of dedicated modes of transport such as rail or the benefits of trans-loading. Trans-load means transferring a shipment from one transportation mode to another. For example, the company may use rail for initial shipment, then transfer to truck for last mile delivery. As further discussed by Donelly, rail is the most attractive land-based transportation mode for long-distance shipment. Yet, its on-time delivery and quality still lag behind truck transportation. This has driven companies to look into and use trans-loading in their supply chains. Also, intermodal ISO-tanks present cost and quality benefits especially for long distance international transportation, which chemical companies can exploit. However, the true cost of ISO-tank use and overall supply chain operation would depend on whether the forms of storage and transportation a company uses are secured on a contract basis or on the spot market.

The main drivers of rates and thus cost in contracted and spot-market transportation are availability, transit time, capacity utilization and more so volatility of fuel prices. The total marine and inland transport cost to move a 40-foot container from Shanghai, China to Columbus, US was $3000 in the year 2000 when oil prices were $20 per barrel. In 2008, the transportation cost was $8000 with oil prices around $140 per barrel. (Transportation Economics & Management Systems, Inc. 2008)

Karimi, Srinivasan & Han (2002) mentioned that logistics costs can account for up to 20% of purchasing costs in the global chemicals industry. This has driven continuous studies in chemical product logistics to contain/reduce product delivery cost. The costs are generated from all possible modes of transport, such as air, pipeline, marine, rail, and road.

In regard to the types of shipment, Huang and Karimi (2006) define chemical shipping of two forms: deep-sea and short-sea. They defined deep-sea shipping as the transportation between continents in deep seawater, where large multi-compartment tankers move large volumes of cargos between major ports and manufacturers. Short-sea shipping focuses on regional areas. The company of interest in this thesis, TopChem Inc., engages in deep-sea shipment for its chemical products.

One challenge in chemical product transportation is the transit time variability. Vernimmen, Dullaert and Engelen (2007) researched and found that, despite claims by shipping lines that most of their container-ships operate on fixed-day weekly schedules, a large survey recently revealed that over 40% of the vessels deployed on worldwide liner services arrive one or more days behind schedule. Through our research and interviews with experts at TopChem Inc., we discover that parcel tank vessels sailing between the U.S. gulf coast to South America-smaller vessels with up to 42 tank compartments-operate with even higher variability in transit time. This is because there are only three service providers serving this route with little competition. In addition, to fully utilize their capacity, the parcel tank vessels operate with multiple and irregular stops, loading and uploading goods, en route to the final destination. As a result, the transit time can range from 20 to 45 days, posing big challenges for TopChem Inc. to serve its South American customers.

2.1.6. Terminal Service Requirements

Chemical product terminals play a dual role of trans-loading and storing of chemicals. From terminal service providers' perspective, at any given time, several contracts may compete for a storage tank and the optimal allocation of tanks to the contracts is a complex combinatorial issue that the terminal operator must routinely resolve. (Tay, Karimi, Peck and Peh 2005) In a dynamic environment, when current contracts end and new contracts begin, the terminal operator may need to reallocate tanks continually to increase facility utilization, maximize revenue, and minimize costs. If the facility is overloaded and the operator cannot service all orders, then he must select the profitable orders to serve and reject others. In other words, selecting the most profitable contracts and simultaneously assigning tanks to these contracts in a dynamic and optimal fashion is a major problem faced by many third party logistics providers (3PLs). In this thesis, we incorporate terminal costs that TopChem Inc. provides for its different terminal facilities, in determination of the optimal distribution network to minimize C2S.

2.2. Supply Chain Network Models

A Supply Chain Network Model is a mathematical model. This model can be solved using optimization techniques and then analyzed to pick the best solution, which is to determine the optimal location of facilities (warehouses, plants, lines within the plants, and suppliers) and the best flow of products through this facility network structure. (Watson, Cacioppi, Jayaraman, Lewis, 2012)

2.2.1. Network Model Application

Logistics decisions may be divided or grouped in several dimensions based on various criteria such as strategic planning level, network level and operational level. Supply chain networks provide large opportunities for cost reductions through the redesign of the flow of material from a producer to customers. The chemical supply chain specifically is a fruitful area with cost reduction opportunities for the following reasons. (Ferrio 2007)

(1) It represents a significant portion of the total cost to serve customers;

(2) It is very dynamic and constantly changes;

(3) Its complexity often hides a lowest cost option.

Since supply chain networks have a wide range of applications, businesses need to tailor network dimensions to their specific needs.

2.2.2. Network Optimization Problems

Network optimization is concerned with how to efficiently transport material from one point to another in a network, given a number of limiting constraints, such as node capacities and costs between nodes in the network. Network optimization problems can be broadly segmented into the following three categories. (Ahuja, R.K., Magnati and Orlin, 1993)

1. *Shortest path problem*

This category tries to address the questions as how to get from one point to another in the network using the shortest and cheapest path.

2. *Maximum flow problem*

This category aims to answer the questions as how to achieve the highest flow output between nodes in a network given capacity constraints within the network.

3. Minimum cost flow problem

This category is to answer the questions as how to assign flows to the links and through the nodes in a network in the most cost effective way, given a cost per unit of flow in the network.

The minimum cost flow problem has a special characteristic in that it can be seen as the combination of the shortest path problem and the maximum flow problem in the network, with consideration of both link capacities and costs. Specific problem types can be defined from the general categories listed above, including, but not limited to, transportation, convex cost flow, multi-commodity flow, minimum spanning tree, assignment and transshipment problems, etc. In our thesis, we intend to evaluate the SKU-1 network optimization as a minimum cost flow problem (MCFP), and more specifically, as a Production and Transportation Problem (PTP). PTP deals with the problem of how to plan production and transportation in an industry given several plants at different locations and large number of customers of their products. (Lukač, Hunjet, Neralić 2008) Because the objective function and the capacity and cost constraints are usually (but not always) represented by linear relationships and the SKU-1 supply chain is relatively small in scope, our network optimization problem can be solved with linear programming.

2.2.3. Supply Chain Network Designs

Supply chain network design determines the physical configuration and infrastructure of the supply chain. The objective is to design or configure the logistics network in order to minimize annual system-wide cost, including production and purchasing costs, inventory holding costs, facility costs (storage, handling, and fixed costs), and transportation costs, subject to a variety of service level requirements. (Shimchi-Levi, Chen and Bramel 2005)

Research in supply chain network design can be traced back to the early 1970s. Supply chain networks have embraced expanded functionalities, multi-echelon structure and global flows of products and services. Geoffrion and Graves (1974) presented some of the earliest work on approaching the design problem as a mixed integer linear program (MILP). They focused on the design of a distribution system with a single echelon of distribution centers (DCs) connecting production plants to customer zones with an objective to minimize the sum of transportation costs and DC operating costs. Constraints in the model addressed production, and capacities at DC as well as fixed and variable costs. Cohen and Moon (1991) expanded model design by adding a raw material vendor echelon and a piece-wise linear cost model to capture economies of scale in the manufacturing echelon.

Arntzen, Brown, Harrison, and Trafton (1995) explored multi-period modeling for a global supply chain because it not only included production, distribution, and transportation costs, but also dealt with duty, inventory costs, and import restrictions. The objective function was a weighted combination of cost, duty drawback credits, and time required for processing and transportation. Constraints were used to enforce demand satisfaction, material balances, throughput limits, production capacity, inventory limits, and a variety of network configuration limitations.

Tsiakis, Shah, and Pantelides (2001) modeled a supply chain composed of manufacturing plants, a warehouse and distribution center echelons, and customer zones. The model also included a constraint on the use of shared resources between products at the manufacturing sites. The authors presented the use of a scenario planning approach to deal with uncertainty in the parameters of the model.

These examples of network applications and designs have lots of merits and evidence the progress that has been achieved in the field of network design. We use this background knowledge in the development of a network optimization model for SKU-1.

2.2.4. Scenario Analysis

Network optimization models often need to go beyond finding optimal solutions in order to be valuable to businesses that face uncertainties. Scenario analysis is one way to test how the model stands under some extreme settings. Lababidi, Ahmed, Alatiqi , and Al-Enzi (2004) demonstrated in their paper a model of a typical petrochemical company that manufactures different grades of polyethylene, operates at a single site and uses two reactors. Uncertainties are then introduced in demand, market prices, raw material costs, and production yields by constructing ten scenarios with different perimeter inputs. The main conclusion of this study is that uncertainties have a dramatic effect on the planning decisions of the petrochemical supply chain. Market demand was found to be the most important parameter that exhibits a strong impact on the production decisions, followed by production yields. Because the product in this thesis, SKU-1, faces similar market conditions, we conduct scenario analyses to evaluate how changes in market conditions impact the results of our deterministic model.

3. Methodology

We first elaborate on the traditional transshipment network model and how its limitations affect this project. We then explain in detail how our optimization model is set up by defining the objective function, model parameters and various constraints. Next, we build the model in Excel Solver to find an optimal solution, and provide general insights based on scenario analysis.

3.1. Traditional transshipment model

Traditional transshipment models involve various nodes and arcs connecting to each other. Nodes can be either supply nodes (sending nodes) or demand nodes (receiving nodes). There are different costs to move products from one node to another with different arcs. The objective is to find the optimized shipment solution so that demand in each node is satisfied while aggregated cost is minimized.

While this approach is a good starting point for our project, there are some limitations. The model does not take product manufacturing cost into consideration. In this thesis, production costs vary among different manufacturers, which can affect selection of supply nodes and product flow. We therefore, need to expand the transshipment model to incorporate the manufacturing cost.

3.2. TopChem Inc.SKU-1 SC network model

To further define the model setup, the following notations will be used throughout this paper.

3.2.1. Model parameters

P_i: Manufacturing cost per ton at node i

C_{ij}^{K}: Transportation cost per ton from node i to j under transportation modes K

R_j: Railcar cost per ton at node j

T_j: Terminal cost per ton at node j

I_j: Inventory holding cost per ton at node j

X_{ij}^K: Total tonnage transported from node i to node j under transportation modes K

K: Transportation modes $\begin{pmatrix} 1: Rail \\ 2: Truck \\ 3: Pipeline \\ 4: Ocean\ Parcel \\ 5: Ocean\ Container \end{pmatrix}$

S_i: Manufacturing capacity at node i

D_j: Annual demand of customer j

3.2.2. Objective function

Our objective function is to minimize the total supply chain costs of SKU-1 from manufacturers to customers. It is defined as:

$$\sum_{i\in M}\sum_j\sum_K P_i X_{ij}^K+\sum_i\sum_j\sum_K C_{ij}^K X_{ij}^K+\sum_i\sum_j\sum_{K\in 1} R_j X_{ij}^K+\sum_i\sum_{j\in T}\sum_K T_j X_{ij}^K+\sum_i\sum_{j\in T}\sum_K I_j X_{ij}^K$$

Whereas M is a set of manufacturers and T is a set of terminals.

3.2.3. Constraints

We define two constraints in the model. The first is the supply constraint, which is the maximum output that each manufacturer can produce based on its production capacity. The second is the demand constraint, which is the minimum amount that customers can receive from terminals or manufacturing plants. They are shown below. We do not define terminal constraints since TopChem Inc. has enough terminal capacity to handle current customer demands.

$$\sum_j\sum_K X_{ij}^K \le S_i \quad i \in Manufacturer$$

$\sum_i \sum_K X_{ij}^K \geq D_j \quad j \in Customers$

3.2.4. Total C2S and Extra Berth Cost

As explained earlier, berth cost is the port cost when the product needs to be called to port en route to destination port. The charge is $18,500 per shipment from Europe to the U.S. gulf coast, for a typical shipment quantity of 2600 tons. Once our network model determines the total quantity shipped from Europe to Gulf Coast, we calculate the incurred berth cost (as shown below) by first dividing total shipped quantity by 2600, then multiplying with $18,500.

$[(\sum_i \sum_j \sum_K X_{ij}^K)/2{,}600]*18{,}500$

Where:

K: Ocean Parcel Shipment

i: Europe Manufacturing Facility

j: Gulf Coast Terminal

The berth cost is added to the supply chain cost calculated by our model to come up with the total cost to serve.

3.3. Excel Solver for optimization solution

We use Excel to build the optimization model with inputs of all the model parameters, objective function and various constraints as defined above. We then run Solver to find the optimization solution that minimizes aggregate supply chain costs.

3.4. Scenario analysis

We build three scenarios to test the effects of shifts in supply that TopChem Inc. may face. The baseline scenario has the Midwest, South East and Europe refineries contracted to supply SKU-1. In scenario 1, we set up our supply parameter in such a way that the Midwest facility stops supplying SKU-1 completely. This forces the model to run the optimization based on supply availability and capacities at its South East and Europe facilities. In scenario 2, we take out both the Midwest and the South East supplies, forcing the model to utilize the Europe facility to satisfy the global demand. In each scenario, we run the optimization solution and compare results for further analysis.

4. Data Analysis

TopChem Inc. provided us with data to use in the optimization model that we build. The data include cost components of C2S, such as manufacturing cost, terminal cost, inventory holding cost, transportation cost of different modes, and berth cost, if applicable. The data also include manufacturing capacities, terminal capacities and customers demand. We obtain other data that are relevant, yet not provided, such as distances between nodes, from publicly available and reliable sources.

4.1. Model Inputs

Various cost components, manufacturing and terminal capacities, and customer demand, are formulated into our network optimization model. They are explained as follows.

4.1.1. Supply Capacity and Costs

The South East refinery could be contracted to supply up to 11,000 MT per year. This capacity is enough to meet total demand. As previously mentioned, TopChem Inc. also sourced some SKU-1 from another manufacturing facility in the Midwest and there is an option to bring the Europe supply into the network. In our optimization model, we evaluate the C2S given supply capacity of 11,000 MT per year at all three supply locations (South East, South East, and Europe) in three scenarios – Supply available from all three options, Supply discontinued from the Midwest and Supply available from Europe only. Table 4-1-1 shows the variable manufacturing cost for SKU-1 at all three locations.

Table 4-1-1 SKU-1 Supply Locations and Costs per MT

Manufacturer	Manufacturing Cost
South East	$1,005.00
Europe	$1,060.00
Midwest	$1,005.00

4.1.2. Terminal Costs and Capacity

TopChem Inc. contracts or builds terminal storage tanks at strategic locations to distribute products globally. Table 4-1-2a, b, and c shows the terminal capacities, handling, and inventory costs at North East, Gulf Coast, West Coast, and South East Canada locations. Terminal cost includes both fixed and variable storage costs that are negotiated under contract. The inventory holding cost is the carrying cost that the company incurs before TopChem Inc. delivers the product or the product is picked up by customers. The company averages terminal handling and inventory costs and charges the cost on a per ton basis if product is distributed from terminals.

Normally, terminal capacity is set, once determined at the beginning of a business cycle. Distribution is then based on shipment frequency to terminal and/or using temporary storage in case of excess shipment to the terminals.

Presently, SKU-1 customers place purchasing orders monthly. For product distributed through terminals, the company rails the product to each terminal (or by parcel tank ships from Europe to Gulf Coast terminal), then either customers pick up or the company delivers product from terminals to customers. Table 4-1-2a shows the terminal capacities in the network. The usable capacity is defined as the difference between storage capacity and the required heel, which is the minimum amount of product that cannot be extracted from a tank under normal operations or is left in the tank for safety reasons. Table 4-1-2b and 4-1-2c show the terminal handling and inventory costs. Figure 4-1-2d provides a snapshot of monthly demand and terminal capacity for the North American terminals. As can be seen, all terminals operate below the set capacity on a monthly basis. This is especially true for Gulf Coast and South East Canada terminals.

Table 4-1-2a SKU-1 Terminal Capacities

Location	Capacity MT	Units	Required Heel (min)	Units	Usable Capacity	Units
North East	330	MT	15	MT	315	MT
Gulf Coast	2884	MT	326	MT	2558	MT
West Coast	440	MT	29	MT	411	MT
South East Canada	630	MT	48	MT	582	MT

Table 4-1-2b SKU-1 Terminals Handling Costs per Metric Ton

Terminal	Terminal Handling Cost
South East Canada	$27.21
North East	$37.48
West Coast	$48.79
Gulf Coast	$33.70
South America	$80.00

Table 4-1-2c SKU-1 Inventory Holding Costs per Metric Ton

Terminal	Inventory Holding Cost
South East Canada	$29.78
North East	$13.38
West Coast	$19.56
Gulf Coast	$9.40
South America	$0.00

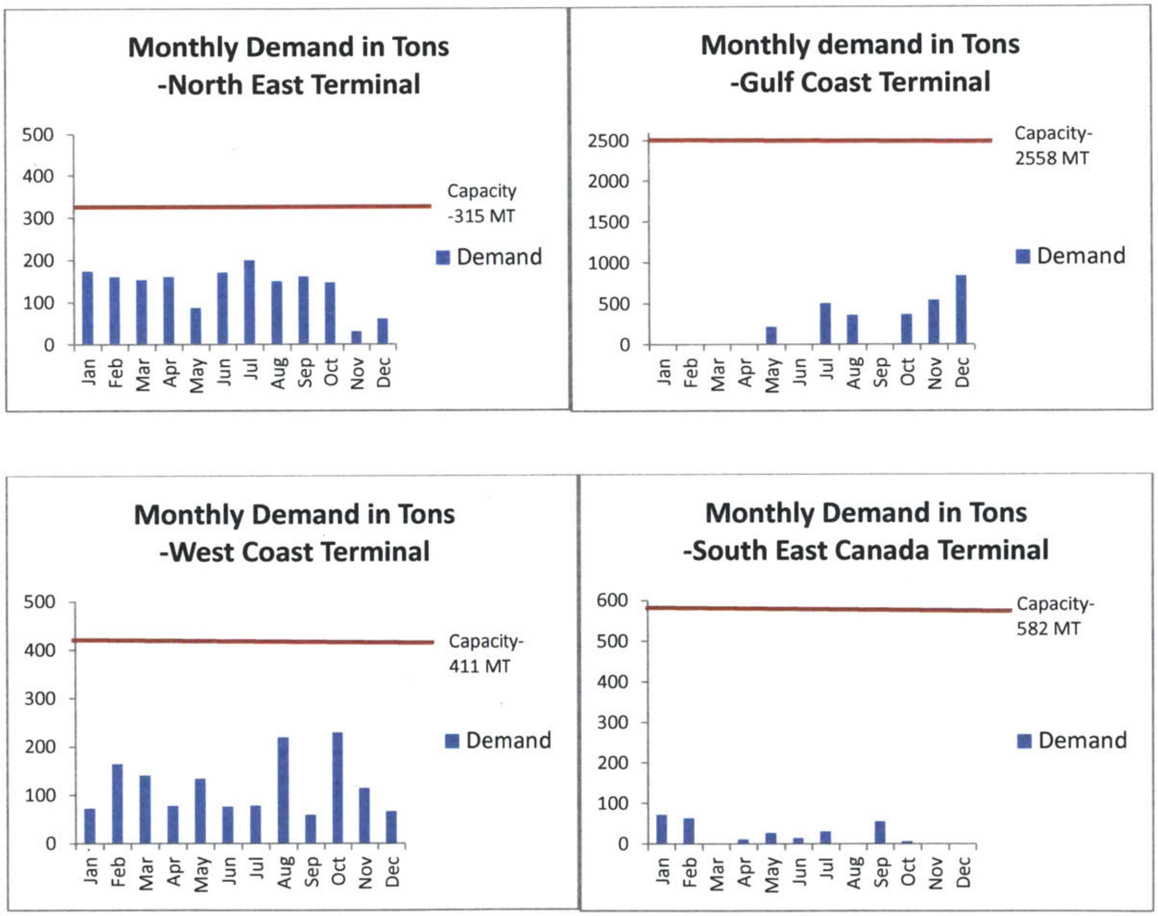


Figure 4-1-2d Monthly Demand at Terminals vs. Terminal Capacity

4.1.3. Customers' Demand

Customers place their order quantity for the following month by the 20th of each month. The company aggregates all the demand and places orders to the refineries. The product is then distributed from the refineries directly to customers or shipped to terminals where customers either pick up or the company delivers to the customer facility.

In 2012, TopChem Inc. sold 10,500 MT of SKU-1, of which North American sales accounted for 73% and South America 27%. While the company used one distribution point in South America, its customer base in North America is fairly dispersed with 24 customers spread in 50 locations. Some customers were served in multiple locations while some locations had multiple customers. The demand was highly concentrated to its key customers. Its top 5 customers accounted for 74% of the total volume. Its top 10 customers accounted for 87%. Figure 4-1-3a illustrates annual customer demand and cumulative percentage of the total demand.

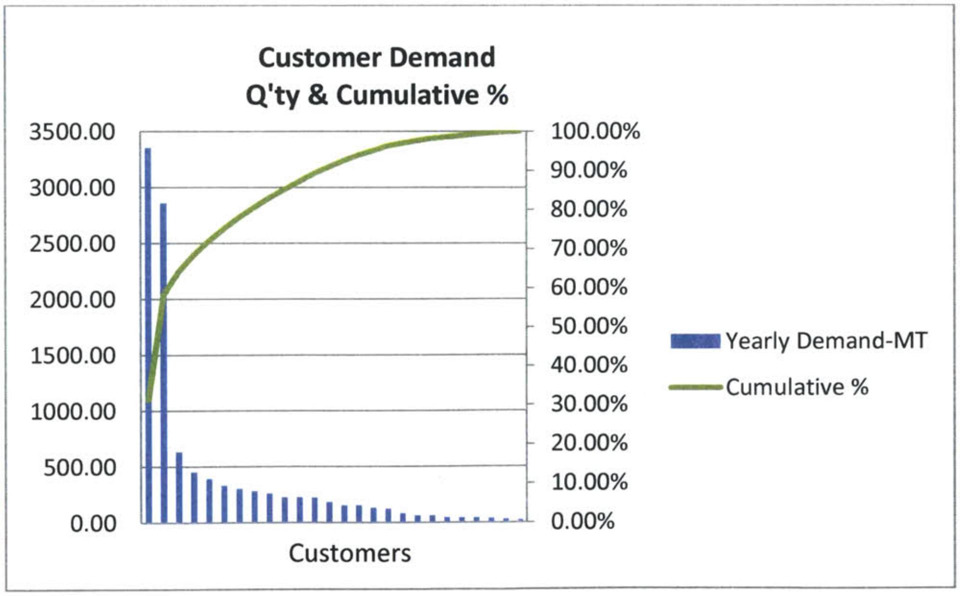


Figure 4-1-3a Top 10 Customers Demand Quantity and Cumulative Percentage

Demand for SKU-1 was steady throughout the year with slight monthly variances. The slowest months were from January to April, while demand typically increased in the second half of the year with the highest demand recorded in November and December. Figure 4-1-3b shows the monthly demand breakdown.

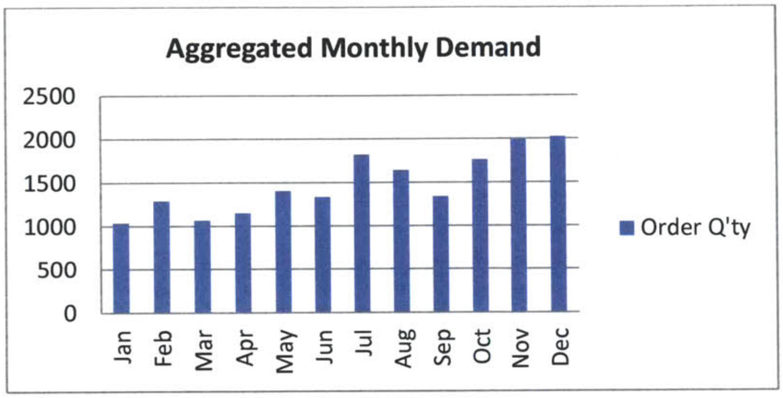


Figure 4-1-3b SKU-1 Aggregated Monthly Demand, Metric Tons

Demand from South America, though, was very seasonal. As shown in Figure 4-1-3c, South America demand was concentrated on the 2nd half of the year with zero orders booked from January to April.

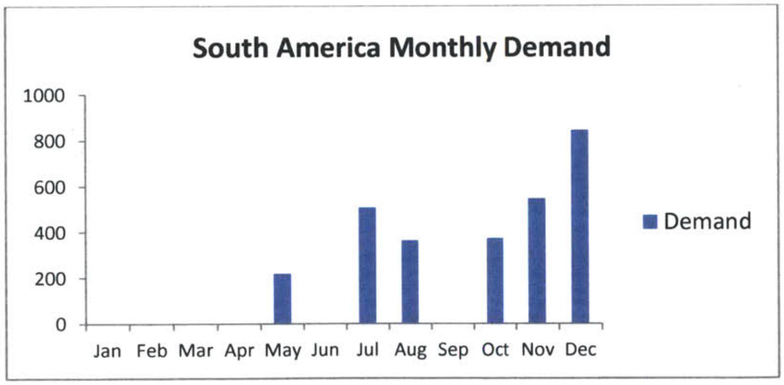


Figure 4-1-3c SKU-1 Monthly Demand for South America, Metric Tons

4.1.4. Transportation Costs

From the manufacturing facilities or terminals, SKU-1 is transported by either rail or road truck. If sourced from Europe, the product is shipped by ocean to the Gulf Coast terminal or directly to South America. The company also uses rail to deliver SKU-1 to a few customers directly. In its West Coast terminal, TopChem Inc. also has the option to use pipeline to deliver SKU-1 to a customer located adjacent to the terminal. For its South America customers, the company ships product by ocean to the South America terminal either from the Gulf Coast terminal or the Europe manufacturing facility. Figure 4-1-4a shows product shipment broken down by mode of transportation.

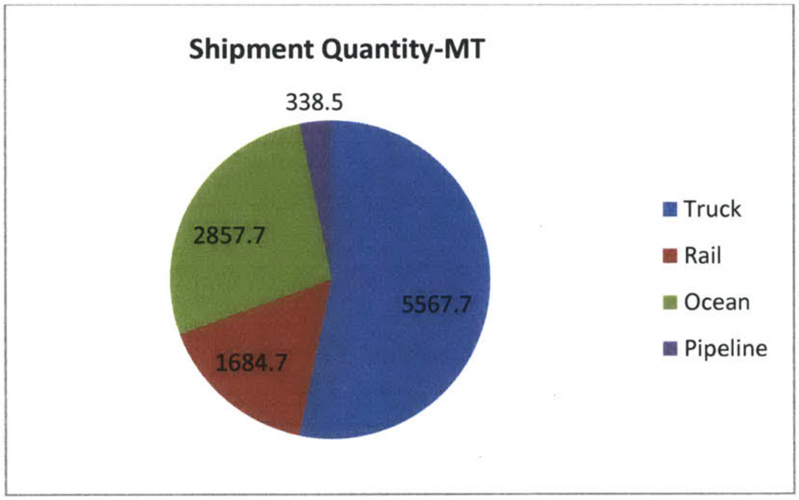


Figure 4-1-4a Shipment Quantity with Transportation Modes

TopChem Inc. currently serves each customer on dedicated transportation routes if the company has delivery agreements with the customer. For customer pick-up, transportation ends at either the manufacturing facility or terminal, depending on the pickup facility. With the Midwest facility ceasing to supply SKU-1, all customers that were served from Midwest must be served from somewhere else. Possible options include other terminals, the South East manufacturing facility, or the European manufacturing facility through the Gulf Coast terminal.

Since some of the transportation costs linking these routes are not readily available, we use linear regression to estimate the transportation costs for these routes. The regression is done for truck rates and for rail freight rates.

We define distance as the independent variable and transportation rate as the dependent variable with the linear function of Rate=A+B*Distance.

With the available data on truck rates and distance between origin and destination, we get the linear regression function of Rate=25.703+0.1764*Distance with an adjusted R^2 of 0.9503, which means the regression model explains 95.03% of the actual truck rate. Figure 4-1-4b shows the regression results.

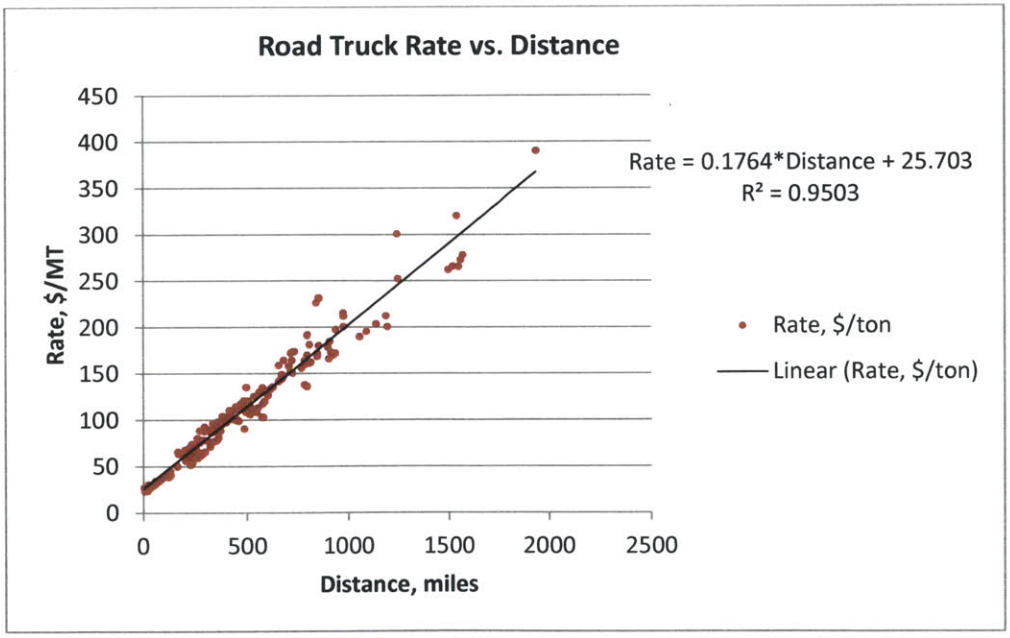


Figure 4-1-4b Road Truck Transportation Rates vs. Distance

Three customers are served by direct rail shipment from either the Midwest or the South East production facilities. With the Midwest facility out of the picture, these customers will in the future be served by direct rail from either the South East facility or the Gulf Coast terminal. We use available rail data containing rail transportation rates and distance from plants to terminals, terminal to terminal and terminal to customer to determine linear equations for rail freight rates as the dependent variable and distance as the independent variable. Figure 4-1-4c shows the result of the regression. We then use the linear equation to determine other rates that are needed in the model but are not available in the original data.

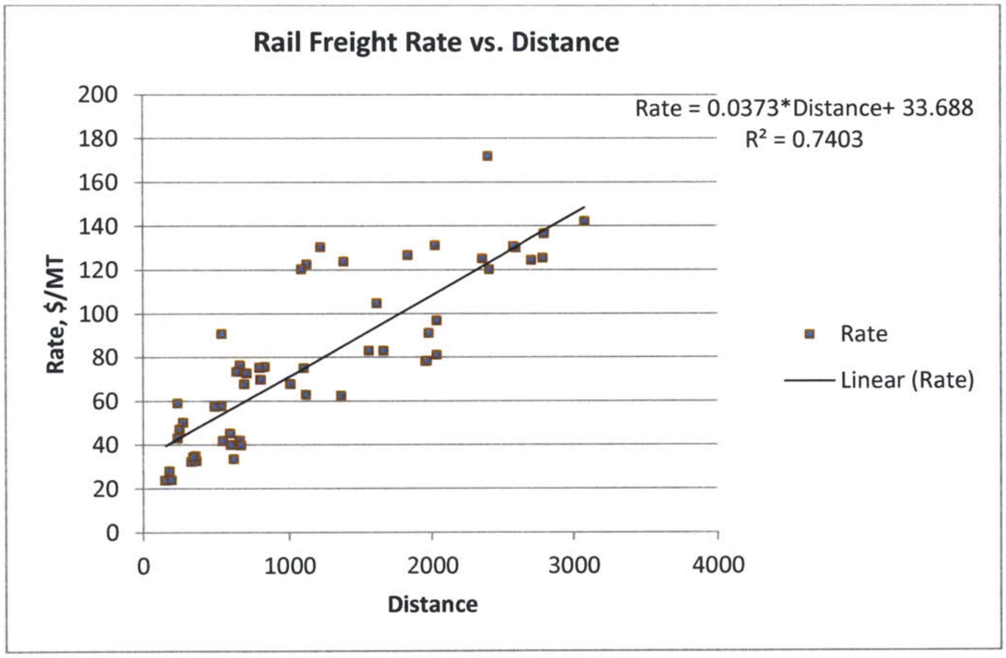


Figure 4-1-4c Rail Tank Transportation Rates vs. Distance

4.1.5 Railcar Cost

Railcar cost is incurred when the company ships SKU-1 by rail from manufacturing facilities to terminals or from manufacturing facilities to a few selected customers directly. If the company ships SKU-1 from Europe, the rail car cost is incurred for shipments from the Gulf Coast terminal to other terminals and to the few direct rail customers. The railcar rates do not show a linear relationship to distance as the freight rates do. Instead, to determine railcar costs not available in the data provided by TopChem Inc., we calculate them from available railcar rates on a per mile basis. To do this, we calculate the costs from the Gulf Coast terminal based on the per mile rate from the South East manufacturing facility to those same locations. For Gulf Coast terminal to Customer I and South East manufacturing facility to Customer I, we use the per mile rate for the only rate available, from Midwest manufacturing facility to Customer I. The results are shown in Table 4.1.5.

Table 4-1.-5 Railcar Cost

Available Rail Car Costs

From	To	Rail Car Cost (per MT)	Distance
South East	North East	$17.60	1382
South East	West Coast	$22.22	1832
South East	Gulf Coast	$23.58	276
South East	Customer I|ELIZABETH	$17.59	1386
South East	Customer I|FAIRFIELD	$46.51	2213
Midwest	South East Canada	$9.08	348
Midwest	North East	$12.69	806
Midwest	West Coast	$17.58	2025
Midwest	Customer I|ELIZABETH	$26.15	795
Midwest	Customer P|PORTLAND	$20.38	2175
Gulf Coast	West Coast	$17.77	1558
Gulf Coast	South East Canada	$17.58	1364

Estimated Rail Car Costs			
From	**To**	**Rail Car Cost (per MT)**	**Distance**
Gulf Coast	Customer P|PORTLAND	$21.07	2249
Gulf Coast	Customer I|ELIZABETH	$20.56	1620
Gulf Coast	Customer I|FAIRFIELD	$40.75	1939
Gulf Coast	North East	$20.57	1615
South East	Customer P|PORTLAND	$24.10	2572
South East	South East Canada	$15.71	1219

4.1.6. Transportation Costs for Pick up Customers

Transportation costs are available for customers to whom TopChem Inc. delivers SKU-1 by road, truck or rail. However, no data is available on costs incurred by the customers that pick their orders from TopChem Inc.'s plants or terminals. In order to evaluate where these customers should pick product, we use the transportation equations developed from available data provided by TopChem Inc. to estimate these rates, given the distance from dispatch sites to customer locations. This way, the optimization model selects the ideal pick-up location for each customer.

4.2. Scenario Setup

We run Solver to find the optimization solution based on current parameter settings. That is, we have three manufacturing facilities, five terminals, a group of customers with known demand and different costs incurred from node to node. The optimization solution finds the lowest aggregated costs but does not tell us how the net flow and the corresponding cost-to-serve change if some of the parameters are adjusted.

We use scenario analysis to study some potential events and their alternative outcomes. Scenario analysis complements the optimization solution by presenting a scope of future developments.

To analyze the total cost-to-serve for the entire SKU-1 network, we set up three scenarios as shown in Table 5-2 below. The Baseline scenario is the supply network with operational production capacity at the South East, European and Midwest manufacturing facilities. Scenario 1 evaluates the cost with the Midwest taken out of the system and Scenario 2 does the same with only Europe as the source of production.

Table 4-2 Model Scenario Setup

	Baseline Scenario	Scenario 1	Scenario 2
Scenario Description	**All Available**	**No Midwest**	**No Midwest & South East**
Manufacturing (MT)			
South East	11,000	11,000	0
Europe	11,000	11,000	11,000
Midwest	11,000	0	0
% Change from Baseline			
South East	0%	0%	-100%
Europe	0%	0%	0%
Midwest	0%	-100%	-100%

5. Results and Discussion

5.1. Total Cost to Serve

Table 5-1 shows the results, which indicate that the total cost-to-serve increases by 2% in scenario 1 when the Midwest is not included as a production source. Compared to the baseline scenario, the total C2S is increases by $304.640.56 in scenario 1 representing a net increase of $29.20 in C2S per ton. In scenario 2, where only Europe supplies product for North and South America, the total C2S increases by 13%, an increase of $1,646,535.95 total and $157.80 per metric ton. We analyze the various contributors to the total C2S in the following sections.

Table 5-1 Model Results-Total Cost to Serve by Scenario

	Baseline Scenario	Scenario 1	Scenario 2
Total Cost-to-Serve	$12,215,201	$12,519,841	$13,861,737
Demand	10,434	10,434	10,434
Cost-to-Serve/MT	$1,170.71	$1,199.91	$1,328.52
% Change from Baseline	0%	2%	13%

5.2. Cost Driver Analysis

Table 5-2a shows total C2S broken down to individual cost drivers. The cost drivers are categorized as follows: manufacturing, terminal handling and inventory, stock movement to terminals, freight to customers (including direct rail), rail car to terminals, and rail car to customers (direct rail). Manufacturing costs contribute the highest proportion at an average of 83.1% of total C2S in all 3 scenarios. The next biggest contributor is stock movement to terminals costs at 6.9%. Inventory holding, and Rail car costs terminals and Rail Car direct to customers contribute, on average, less than 1% each to the total C2S.

Table 5-2a Model Results-Cost Drivers as Percentage of Total C2S

	Scenario 1	**Scenario 2**	**Scenario 3**
	Baseline scenario	**No Midwest**	**No Midwest or South East**
Total Cost-to-Serve	$12,215,200.92	$12,519,841	$13,861,737
Cost Name			
Manufacturing	$10,486,291	$10,486,291	$11,060,167
Terminal Handling	$444,292	$470,736	$852,725
Inventory	$77,201	$88,456	$160,948
Stock Movement to Terminals (Including Berth Cost)	$646,905	$821,539	$1,241,975
Freight to Customer (Including Direct Rail)	$400,485	$476,625	$441,916
Rail Car to Terminals	$115,980	$143,400	$68,268
Rail Car to Customer (Direct Rail)	$44,048	$32,795	$35,738
Cost as percentage of Total Cost-to-Serve			
Manufacturing	85.8%	83.8%	79.8%
Terminal Handling	3.6%	3.8%	6.2%
Inventory	0.6%	0.7%	1.2%
Stock Movement to Terminals (Including Berth Cost)	5.3%	6.6%	9.0%
Freight to Customer (Including Direct Rail)	3.3%	3.8%	3.2%
Rail Car to Terminals	0.9%	1.1%	0.5%
Rail Car to Customer (Direct Rail)	0.4%	0.3%	0.3%

Table 5-2b and Figures 5-2a and 5-2b show how the cost drivers change in scenario 1 and 2 compared to the baseline scenario. In the following sections, we lay out the analysis of the changes through the different scenarios.

Table 5-2b Model Results-Costs Drivers by Scenario

	Scenario 1	**Scenario 2**	**Scenario 3**
	Baseline scenario	**No Midwest**	**No Midwest or South East**
Total Cost-to-Serve	$12,215,201	$12,519,841	$13,861,737
Cost Name			
Manufacturing	$10,486,291	$10,486,291	$11,060,167
Terminal Handling	$444,292	$470,736	$852,725
Inventory	$77,201	$88,456	$160,948
Stock Movement to Terminals (Including Berth Cost)	$646,905	$821,539	$1,241,975
Freight to Customer (Including Direct Rail)	$400,485	$476,625	$441,916
Rail Car to Terminals	$115,980	$143,400	$68,268
Rail Car to Customer (Direct Rail)	$44,048	$32,795	$35,738
Cost as percentage of Total Cost-to-Serve			
Manufacturing	0%	0%	5%
Terminal Handling	0%	6%	92%
Inventory	0%	15%	108%
Stock Movement to Terminals (Including Berth Cost)	0%	27%	92%
Freight to Customer (Including Direct Rail)	0%	19%	10%
Rail Car to Terminals	0%	24%	-41%
Rail Car to Customer (Direct Rail)	0%	-26%	-19%

Figure 5-2a Model Results-Manufacturing Costs by Scenario

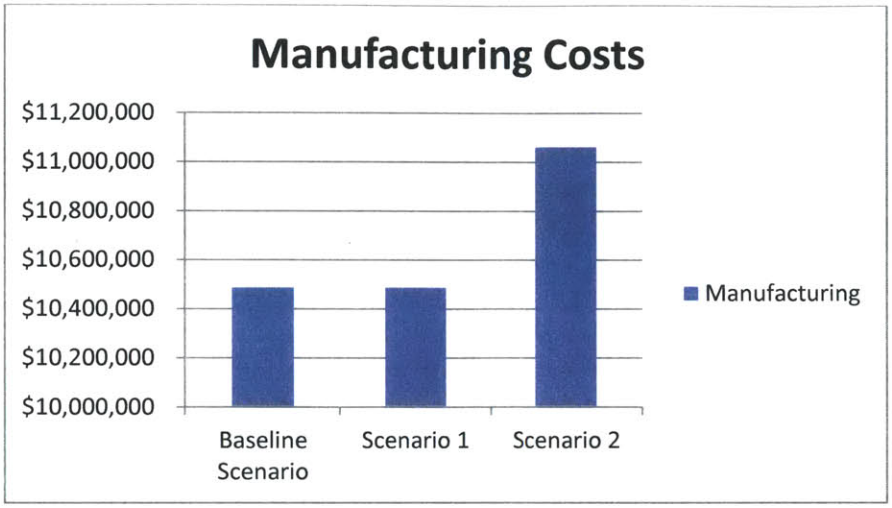
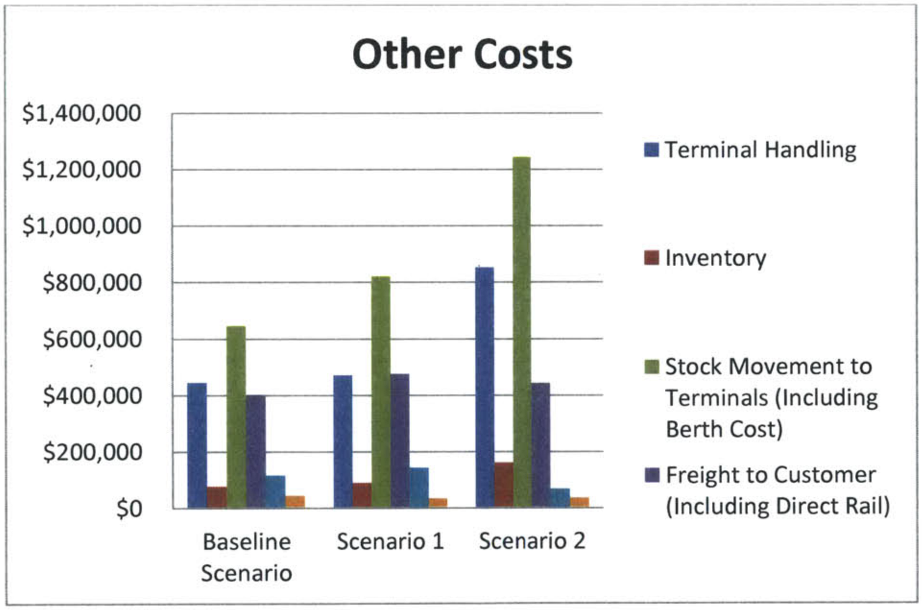


Figure 5-2b Model Results-Other Costs by Scenario



Manufacturing

In scenario 1, manufacturing costs stay the same as in the baseline scenario because all the SKU-1 sourced from North American manufacturing at a variable manufacturing cost of $1005/MT. Manufacturing costs increase by 5% in scenario 2 because the whole supply of SKU-1 comes from Europe, where the variable manufacturing cost is $1060/MT, 5% higher than in North America.

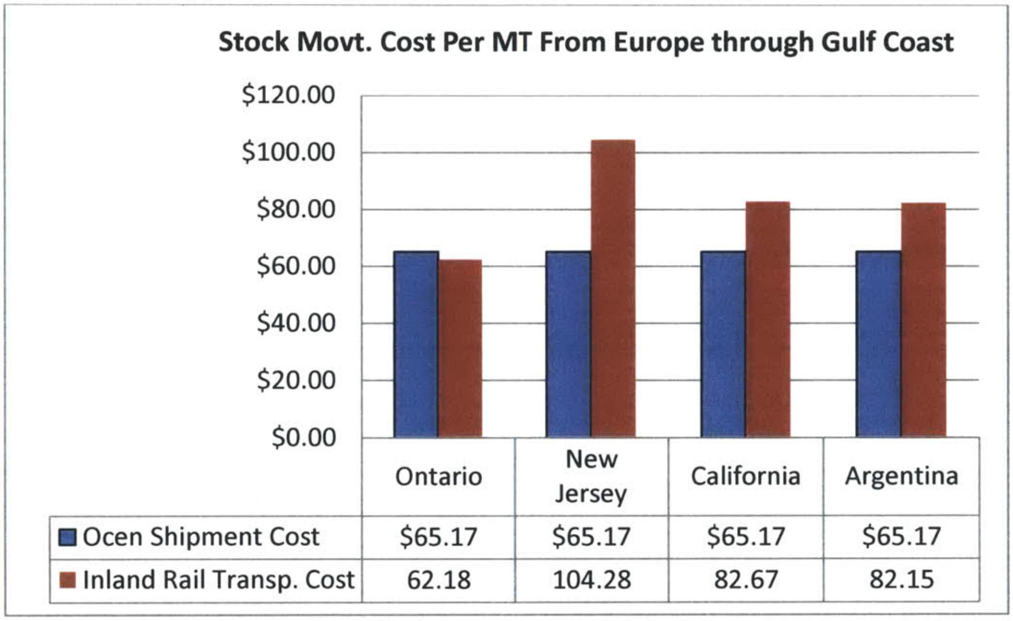
Terminal Handling and Inventory

Terminal handling costs increase by 6% from $444,292 to $470,736 and inventory costs increase by 15% from $77,201 to $88,456 in scenario 1 compared to the baseline scenario. This is because just 7% of the volume previously fulfilled from Midwest is fulfilled from other terminals (1% from South East Canada and 6% from the North East). The majority of the Midwest demand is fulfilled from the South East production facility. These results show that the South East manufacturing facility provides a more cost effective way to serve former Midwest facility customers than terminals do because product has fewer touches and there are no inventory or terminal handling costs involved. This offsets savings that may be achieved by sending the product by rail to a terminal, and then on to the customers. In scenario 2, terminal handling costs go up by 89% from $444,292 to $852,725 and inventory costs by 108% from $77,201 to $160,948, compared to the baseline scenario. The costs in scenario 2 are higher because all the supply from Europe comes through the Gulf Coast terminal incurring extra berth cost, terminal and inventory costs. These costs are charged to all customers, while additional costs are charged for product that moves on to be distributed from other terminals.

Stock Movement to Terminals

In scenario1, stock movement costs to terminals increase by 27% from $646,905 to $821,539 as compared to the baseline scenario, partly because 25% of demand fulfilled from Midwest in baseline scenario is fulfilled from the South East Canada and North East terminals in scenario 1. The rest is fulfilled from the South East manufacturing facility. The increase is also attributed to the fact that all the SKU-1 supply is shipped to the terminals from South East facility, resulting in higher costs for terminals that were cheaper to supply from the Midwest. In scenario 2, stock movement costs are 92% higher than in the baseline scenario, $1,241,975 compared to $646,905, mainly due to ocean shipment cost from Europe. Figure 5-2b shows how the individual components add up to the stock movement costs per ton to each terminal in scenario 2.

Figure 5-2c Model Results-Europe to Terminals Stock Movement Cost by Component



	Ontario	New Jersey	California	Argentina
🟦 Ocen Shipment Cost	$65.17	$65.17	$65.17	$65.17
🟥 Inland Rail Transp. Cost	62.18	104.28	82.67	82.15

Freight to Customers (Including Direct Rail)

In scenario 1, freight costs to customers for both road truck and direct rail shipments increase by 19% from $400,485 to $476,625, as compared to the baseline scenario. This can be attributed to higher freight rates due to longer transit distances from the South East than from the Midwest. In scenario 2, customer freight costs increase by 10% from $400,485 to $441,916 because of longer transit distances from the Gulf Coast and hence higher freight costs. The increase in scenario 2 is lower than scenario 1 because transportation rates from the Gulf Coast to customer locations are, on average, lower than from South East.

Rail Car to Terminals

Rail car to terminal costs increase by 24% in scenario 1 as opposed to the baseline scenario, from $115,980 to $147,696 because the product that was sourced from the Midwest in the baseline scenario is now shipped from the South East manufacturing facility only, travelling longer distances and incurring higher transportation rates. In scenario 2, rail car to terminal costs decrease by 41% from that in baseline scenario 1, $115,980 vs. $68,268, due to generally lower rail car costs per ton from the Gulf Coast to other terminals than from the South East.

Rail Car to Customers (Direct Rail)

Rail car to customer costs decrease by 26% in scenario 1 compared to the baseline scenario, $44,048 vs. $32,795. In scenario 2, rail car costs to customers at $35,738 are 19% lower than in baseline scenario at $44,048. These costs decrease because rail car costs from the Gulf Coast terminal to customers across North America are, on average, lower than from the Midwest and South East manufacturing facilities.

5.3. Product Flows Analysis

Manufacturing

The increase in costs is also reflected in changes in product flows through the network as shown in Tables 5-3a, 5-3b, and 5-3c. In the baseline scenario, the South East facility provides 59% and the Midwest provides 49% of the total supply to meet demand. The South East facility provides 100% of the supply in scenario 1 and Europe provides 100% of the supply in scenario 2.

Terminals

With the Midwest supply excluded from the network in scenario 1, product flow increases through the South East Canada and the North East terminals by 39% and 56% respectively. In scenario 2, Product flow through the Gulf Coast terminal increases by 265% because the terminal handles all the SKU-1 from Europe before distributing further downstream. Also, the South East Canada terminal handles 58% more product and the North East terminal handles 56% more product, similar to scenario 1. The increase in volumes in scenario 1 and 2 compared to the baseline scenario is because of additional volume from former Midwest customers. To illustrate, in scenario 2, 84% of the product handled at Midwest and South East is now handled at the Gulf Coast terminal while the rest is handled at the South East Canada and North East terminals. There are no changes in quantity of SKU-1 handled at the West Coast and South America terminals.

Dispatch to Customers

In scenario 1, quantity dispatched to customers increases at three dispatch sites: South East manufacturing facility by 121%, South East Canada by 39% and North East by 56%. This suggests that it is cheaper to serve the majority of the Midwest plant customers (in the baseline scenario) from the South East plant than through the terminals.

In scenario 2, all of the product from Europe comes in to the Gulf Coast terminal and is then distributed onwards to other terminals. Also, as already mentioned in the terminals section, 84% of demand fulfilled directly by the South East and Midwest dispatch sites in the baseline scenario is now fulfilled from the Gulf Coast terminal and the balance is fulfilled from the South East Canada and North East terminals. Product flows to and from the West Coast and South America terminals remain unchanged through scenarios 1 and 2. In addition, no product flows from Europe directly to South America in all three scenarios. This indicates that the cost for shipment through the Gulf Coast terminal, including the extra berth cost, is cheaper than that of direct shipment from Europe to South America.

Table 5-3a Model Results-Flows from Manufacturing Plants

	Baseline Scenario	**Scenario 1**	**Scenario 2**
Total Supply (MT)	10,434	10,434	10,434
Manufacturing Facility (MT)			
South East	6,118	10,434	0
Europe	0	0	10,434
Midwest	4,316	0	0
% of Total Supply			
South East	59%	100%	0%
Europe	0%	0%	100%
Midwest	41%	0%	0%

Table 5-3b Model Results-Flows from Terminals

	Scenario 1	**Scenario 2**	**Scenario 3**
	Baseline scenario	**No Midwest**	**No Midwest or South East**
Terminal Product Handled (MT)			
South East Canada	231	322	366
North East	1,143	1,783	1,779
West Coast	1,440	1,440	1,440
Gulf Coast	2,858	2,858	10,434
South America	2,858	2,858	2,858
% Change from Baseline			
South East Canada	0%	39%	58%
North East	0%	56%	56%
West Coast	0%	0%	0%
Gulf Coast	0%	0%	265%

South America	0%	0%	0%

Table 5-3c Model Results-Flows from Dispatch Site (Plants and Terminals) to Customers

	Scenario 1	Scenario 2	Scenario 3
	Baseline scenario	No Midwest	No Midwest or South East
Product Dispatch to Customers (MT)			
South East	1,821	4,032	0
Europe	0	0	0
Midwest	2,942	0	0
South East Canada	231	322	366
North East	1,143	1,783	1,779
West Coast	1,440	1,440	1,440
Gulf Coast	0	0	3,992
South America	2,858	2,858	2,858
% Change from Baseline			
South East	0%	121%	-100%
Europe	0%	0%	0%
Midwest	0%	-100%	-100%
South East Canada	0%	39%	58%
North East	0%	56%	56%
West Coast	0%	0%	0%
Gulf Coast	0%	0%	+ 3992 MT
South America	0%	0%	0%

5.4. C2S by Customer

All the C2S drivers described in the previous sections add up to the total C2S for the whole supply chain. However, in order for TopChem Inc. to evaluate C2S and profitability of the business and by individual customer, we show the C2S for each customer on a per ton basis, given their individual demands, transport modes and delivery options. TopChem Inc. incurs all these costs to serve customers unless the customers cover some costs by themselves, such as picking up the product. The costs are then charged to the customers with a markup. Table 5-4a shows how C2S by customer changes in the three scenarios evaluated in this paper. The results indicate that the customers that incur the highest percentage increase in C2S in both scenario 1 and 2, are 1) Those located farther away and from the South East plant and the Gulf Coast terminal, respectively, and 2) Those that are served from terminals but were served from the Midwest or the South East manufacturing facilities in the baseline scenario. For example, Customer A in Table 5-4b picks product from the Midwest production facility in baseline scenario and picks product from the North East terminal in scenario 1, incurring 20% higher costs because of terminal and stock movement costs at the North East terminal that are not present at the Midwest plant. In scenario 2, the Gulf Coast terminal and inventory costs are also added resulting in an even greater increase in costs for Customer A. The North East terminal is located 117 miles from Customer A while the Gulf Coast terminal is 1,519 miles away.

Table 5-4a C2S by Customer

	C2S per MT		
Sold to Customer	Baseline scenario	Scenario 1	Scenario 2
Customer A|LEESPORT|Road Tank Truck|Pick-up	$1,005	$1,201	$1,343
Customer A|READING|Road Tank Truck|Pick-up	$1,005	$1,201	$1,343
Customer B|BEDFORD PARK|Road Tank Truck|TopChem Inc. delivery	$1,032	$1,212	$1,416
Customer C|SAINT PAUL|Road Tank Truck|TopChem Inc. delivery	$1,115	$1,251	$1,443
Customer D|MISSISSAUGA|Road Tank Truck|TopChem Inc. delivery	$1,099	$1,227	$1,372
Customer E|MEDINA|Road Tank Truck|TopChem Inc. delivery	$1,132	$1,263	$1,360
Customer F|MONTREAL|Road Tank Truck|Pick-up	$1,105	$1,208	$1,304
Customer D|MISSISSAUGA|Road Tank Truck|Pick-up	$1,105	$1,208	$1,304
Customer G|BROCKVILLE|Road Tank Truck|TopChem Inc. delivery	$1,179	$1,281	$1,378
Customer H|MONTREAL|Road Tank Truck|TopChem Inc. delivery	$1,221	$1,294	$1,420
Customer I|ELIZABETH|Rail Tank Car|TopChem Inc. delivery	$1,097	$1,160	$1,315
Customer J|WARMINSTER|Road Tank Truck|TopChem Inc. delivery	$1,173	$1,240	$1,382
Customer K|HERMITAGE|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343

Customer I|CARTERET|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer I|ELIZABETH|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer I|TEWKSBURY|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer L |HOLTSVILLE|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer M|BUNOLA|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer M|MORRISVILLE|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer A|READING|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer N|AVENEL|Road Tank Truck|Pick-up	$1,138	$1,201	$1,343
Customer O|LINDEN|Road Tank Truck|TopChem Inc. delivery	$1,164	$1,227	$1,369
Customer I|CARTERET|Road Tank Truck|TopChem Inc. delivery	$1,164	$1,227	$1,369
Customer I|TONAWANDA|Road Tank Truck|TopChem Inc. delivery	$1,220	$1,283	$1,425
Customer B|DORAVILLE|Road Tank Truck|TopChem Inc. delivery	$1,308	$1,372	$1,513
Customer P|PORTLAND|Rail Tank Car|TopChem Inc. delivery	$1,128	$1,173	$1,365
Customer Q|KANSAS CITY|Road Tank Truck|TopChem Inc. delivery	$1,092	$1,110	$1,338
Customer R|MEMPHIS|Road Tank Truck|TopChem Inc. delivery	$1,064	$1,064	$1,326
Customer S|SAND SPRINGS|Road Tank Truck|TopChem Inc. delivery	$1,074	$1,074	$1,314
Customer T|ATLANTA|Road Tank Truck|TopChem Inc. delivery	$1,116	$1,116	$1,365
Customer U|SAND SPRINGS|Road Tank Truck|TopChem Inc. delivery	$1,076	$1,076	$1,314
Customer I|TULSA|Road Tank Truck|TopChem Inc. delivery	$1,077	$1,077	$1,313
Customer I|DENVER|Road Tank Truck|TopChem Inc. delivery	$1,185	$1,185	$1,423
Customer V|TAFT|Road Tank Truck|TopChem Inc. delivery	$1,071	$1,071	$1,284
Customer S|LONGVIEW|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|TULSA|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer S|ELMENDORF|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer S|LANCASTER|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer S|ODESSA|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer S|SAND SPRINGS|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|BATON ROUGE|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer Q|DES MOINES|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer Q|WEST BEND|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer W|MENOMONEE FALLS|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer K|CHANNAHON|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer K|HERMITAGE|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|KANSAS CITY|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer X|SAINT LOUIS|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer Y|CONROE|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|HOUSTON|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|MIDLAND|Road Tank Truck|Pick-up	$1,005	$1,005	$1,200
Customer I|GARLAND|Road Tank Truck|TopChem Inc. delivery	$1,065	$1,065	$1,270
Customer I|BATON ROUGE|Road Tank Truck|TopChem Inc. delivery	$1,077	$1,077	$1,273

Customer I|MIDLAND|Road Tank Truck|TopChem Inc. delivery	$1,117	$1,117	$1,317
Customer Z|LA PORTE|Road Tank Truck|TopChem Inc. delivery	$1,067	$1,067	$1,230
Customer I|HOUSTON|Road Tank Truck|TopChem Inc. delivery	$1,069	$1,069	$1,228
Customer I|FAIRFIELD|Rail Tank Car|Pick-up	$1,222	$1,222	$1,338
Customer AA|LOS ANGELES|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer AB|SANTA FE SPRINGS|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer I|CARSON|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer I|CHANDLER|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer P|PHOENIX|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer B|CITY OF COMMERCE|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer B|PORTLAND|Road Tank Truck|Pick-up	$1,222	$1,222	$1,338
Customer AC|Carson|Pipeline|Pick-up	$1,222	$1,222	$1,338
Customer B|CITY OF COMMERCE|Road Tank Truck|TopChem Inc. delivery	$1,250	$1,250	$1,366
Customer AB|SANTA FE SPRINGS|Road Tank Truck|TopChem Inc. delivery	$1,253	$1,253	$1,369
Customer I|CHANDLER|Road Tank Truck|TopChem Inc. delivery	$1,318	$1,318	$1,434
Customer I|FAIRFIELD|Road Tank Truck|TopChem Inc. delivery	$1,322	$1,322	$1,438
Customer P|PORTLAND|Road Tank Truck|TopChem Inc. delivery	$1,506	$1,506	$1,622
Customer I|FAIRFIELD|Rail Tank Car|TopChem Inc. delivery	$1,265	$1,265	$1,347
Customer AD|Argentina|Bulk tanker|TopChem Inc. delivery	$1,284	$1,284	$1,330

Table 5-4b Percent Change in Customer C2S by scenario

	C2S % Change from Baseline	
Sold to Customer	**Scenario 1**	**Scenario 2**
Customer A|LEESPORT|Road Tank Truck|Pick-up	20%	34%
Customer A|READING|Road Tank Truck|Pick-up	20%	34%
Customer B|BEDFORD PARK|Road Tank Truck|TopChem Inc. delivery	17%	37%
Customer C|SAINT PAUL|Road Tank Truck|TopChem Inc. delivery	12%	29%
Customer D|MISSISSAUGA|Road Tank Truck|TopChem Inc. delivery	12%	25%
Customer E|MEDINA|Road Tank Truck|TopChem Inc. delivery	12%	20%
Customer F|MONTREAL|Road Tank Truck|Pick-up	9%	18%
Customer D|MISSISSAUGA|Road Tank Truck|Pick-up	9%	18%
Customer G|BROCKVILLE|Road Tank Truck|TopChem Inc. delivery	9%	17%
Customer H|MONTREAL|Road Tank Truck|TopChem Inc. delivery	6%	16%
Customer I|ELIZABETH|Rail Tank Car|TopChem Inc. delivery	6%	20%
Customer J|WARMINSTER|Road Tank Truck|TopChem Inc. delivery	6%	18%
Customer K|HERMITAGE|Road Tank Truck|Pick-up	6%	18%
Customer I|CARTERET|Road Tank Truck|Pick-up	6%	18%
Customer I|ELIZABETH|Road Tank Truck|Pick-up	6%	18%
Customer I|TEWKSBURY|Road Tank Truck|Pick-up	6%	18%
Customer L |HOLTSVILLE|Road Tank Truck|Pick-up	6%	18%

Customer M|BUNOLA|Road Tank Truck|Pick-up	6%	18%
Customer M|MORRISVILLE|Road Tank Truck|Pick-up	6%	18%
Customer A|READING|Road Tank Truck|Pick-up	6%	18%
Customer N|AVENEL|Road Tank Truck|Pick-up	6%	18%
Customer O|LINDEN|Road Tank Truck|TopChem Inc. delivery	5%	18%
Customer I|CARTERET|Road Tank Truck|TopChem Inc. delivery	5%	18%
Customer I|TONAWANDA|Road Tank Truck|TopChem Inc. delivery	5%	17%
Customer B|DORAVILLE|Road Tank Truck|TopChem Inc. delivery	5%	16%
Customer P|PORTLAND|Rail Tank Car|TopChem Inc. delivery	4%	21%
Customer Q|KANSAS CITY|Road Tank Truck|TopChem Inc. delivery	2%	23%
Customer R|MEMPHIS|Road Tank Truck|TopChem Inc. delivery	0%	25%
Customer S|SAND SPRINGS|Road Tank Truck|TopChem Inc. delivery	0%	22%
Customer T|ATLANTA|Road Tank Truck|TopChem Inc. delivery	0%	22%
Customer U|SAND SPRINGS|Road Tank Truck|TopChem Inc. delivery	0%	22%
Customer I|TULSA|Road Tank Truck|TopChem Inc. delivery	0%	22%
Customer I|DENVER|Road Tank Truck|TopChem Inc. delivery	0%	20%
Customer V|TAFT|Road Tank Truck|TopChem Inc. delivery	0%	20%
Customer S|LONGVIEW|Road Tank Truck|Pick-up	0%	19%
Customer I|TULSA|Road Tank Truck|Pick-up	0%	19%
Customer S|ELMENDORF|Road Tank Truck|Pick-up	0%	19%
Customer S|LANCASTER|Road Tank Truck|Pick-up	0%	19%
Customer S|ODESSA|Road Tank Truck|Pick-up	0%	19%
Customer S|SAND SPRINGS|Road Tank Truck|Pick-up	0%	19%
Customer I|BATON ROUGE|Road Tank Truck|Pick-up	0%	19%
Customer Q|DES MOINES|Road Tank Truck|Pick-up	0%	19%
Customer Q|WEST BEND|Road Tank Truck|Pick-up	0%	19%
Customer W|MENOMONEE FALLS|Road Tank Truck|Pick-up	0%	19%
Customer K|CHANNAHON|Road Tank Truck|Pick-up	0%	19%
Customer K|HERMITAGE|Road Tank Truck|Pick-up	0%	19%
Customer I|KANSAS CITY|Road Tank Truck|Pick-up	0%	19%
Customer X|SAINT LOUIS|Road Tank Truck|Pick-up	0%	19%
Customer Y|CONROE|Road Tank Truck|Pick-up	0%	19%
Customer I|HOUSTON|Road Tank Truck|Pick-up	0%	19%
Customer I|MIDLAND|Road Tank Truck|Pick-up	0%	19%
Customer I|GARLAND|Road Tank Truck|TopChem Inc. delivery	0%	19%
Customer I|BATON ROUGE|Road Tank Truck|TopChem Inc. delivery	0%	18%
Customer I|MIDLAND|Road Tank Truck|TopChem Inc. delivery	0%	18%
Customer Z|LA PORTE|Road Tank Truck|TopChem Inc. delivery	0%	15%
Customer I|HOUSTON|Road Tank Truck|TopChem Inc. delivery	0%	15%
Customer I|FAIRFIELD|Rail Tank Car|Pick-up	0%	10%
Customer AA|LOS ANGELES|Road Tank Truck|Pick-up	0%	10%
Customer AB|SANTA FE SPRINGS|Road Tank Truck|Pick-up	0%	10%
Customer I|CARSON|Road Tank Truck|Pick-up	0%	10%
Customer I|CHANDLER|Road Tank Truck|Pick-up	0%	10%
Customer P|PHOENIX|Road Tank Truck|Pick-up	0%	10%
Customer B|CITY OF COMMERCE|Road Tank Truck|Pick-up	0%	10%
Customer B|PORTLAND|Road Tank Truck|Pick-up	0%	10%
Customer AC|Carson|Pipeline|Pick-up	0%	10%

Customer B|CITY OF COMMERCE|Road Tank Truck|TopChem Inc. delivery	0%	9%
Customer AB|SANTA FE SPRINGS|Road Tank Truck|TopChem Inc. delivery	0%	9%
Customer I|CHANDLER|Road Tank Truck|TopChem Inc. delivery	0%	9%
Customer I|FAIRFIELD|Road Tank Truck|TopChem Inc. delivery	0%	9%
Customer P|PORTLAND|Road Tank Truck|TopChem Inc. delivery	0%	8%
Customer I|FAIRFIELD|Rail Tank Car|TopChem Inc. delivery	0%	6%
Customer AD|Argentina|Bulk tanker|TopChem Inc. delivery	0%	4%

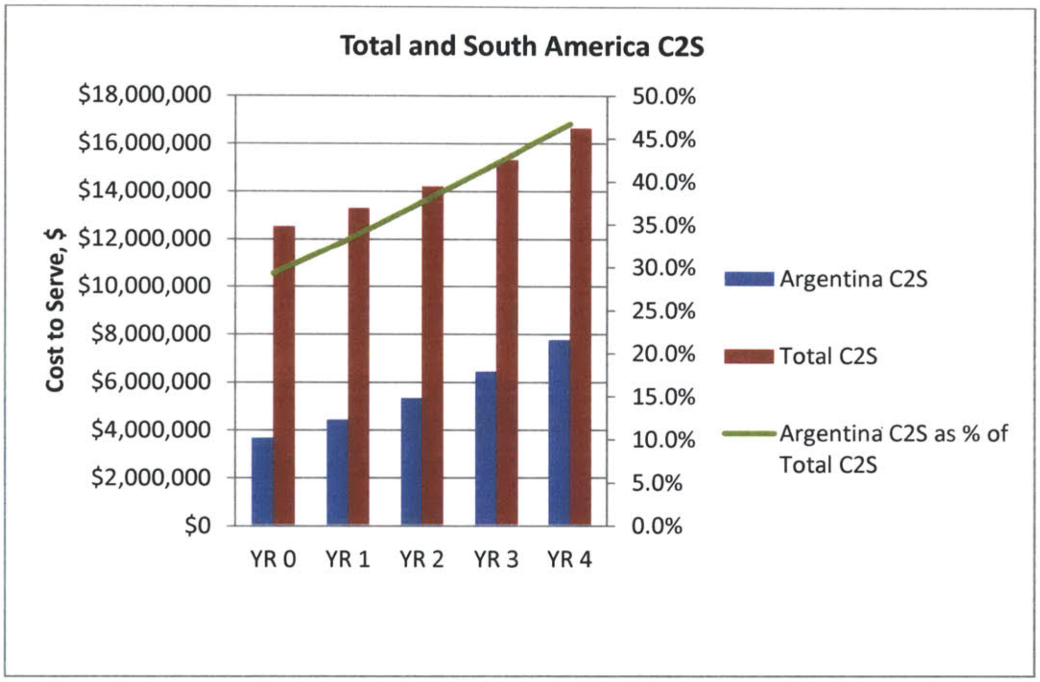
5.5. South America C2S with Increased Demand

To evaluate the effect of the projected demand increase in South America on total C2S, we ran the model with demand in South America increasing over a four-year period to 5926 MT, slightly more than doubling the current demand of 2858 MT, while demand in North America remains flat. We start with the same conditions as scenario 1 with a capacity of 11000 MT per year at both the South East and European plant, but no supply from Midwest plant. We then start with the current annual demand of 2858 MT in South America and increase it by 20% annually for four years, calculating total C2S and the C2S for South America in each year. Table 5-5 shows the demand projections and Figure 5-5 shows the resulting C2S in each year. The results show that as demand in South America increases, the proportion of South America's C2S to the total C2S increases from 29.3% in the current year (YR 0) to 46.7% in 4 years. This means that with the current cost structure in the SKU-1 supply chain and capacity utilization of 95% at the South East plant , the capacity in Europe will have to be used if TopChem Inc. is committed to satisfying all customer demand. In this case, in year 4, almost half of the total C2S will come from serving South America, which accounts for 36% of total global demand.

Table 5-5 South America Demand Increase

	YR 0	YR 1	YR 2	YR 3	YR 4
Total Demand (MT)	10434	13863	14549	15372	16360
South America Demand (MT)	2858	3429	4115	4938	5926

Figure 5-5 South America C2S and Total C2S



6. Conclusion

In this thesis, we have developed a deterministic network optimization model for SKU-1 and established the framework to analyze changes in cost to serve under shifting product supply conditions. We have defined a baseline scenario to represent how TopChem Inc. currently handles the distribution of SKU-1 and created three additional scenarios to evaluate how the total C2S changes from the baseline scenario if 1) Supply capacity shifts and 2) If demand increases in South America while demand in North America remains flat. We have then analyzed individual cost drivers and determine C2S for each customer.

In the baseline scenario, with the Midwest, South East and Europe manufacturing facilities available, the capacity utilization is 39% at the Midwest plant, and 56% at the South East plant. In scenario 1 with the Midwest facility out of the network, South East plant manufacturing capacity utilization increases to 95% while Europe capacity remains unutilized because the capacity in the South East is enough to meet demand and at lower costs. The total C2S in scenario 1 increases by 2%. In scenario 2, where only the European supply capacity is available, the total C2S increases by 13% and manufacturing capacity utilization in Europe increases from 0 to 95%.

The analysis on South America demand shows that TopChem Inc. has to bring in product from Europe as South America demand grows by 20% each year over a four-year period. The European supply capacity is used right from the first year of increased demand. By the fourth year where demand is 5926 metric tons, slightly more than twice the current demand, the C2S to fulfill this demand is 46.7% of total C2S.

Our cost driver analysis shows that, while the total C2S increases by 3% and 12% in scenario 1 and 2, these changes reflect differently in the cost components. Manufacturing costs increase in Scenario 2, but decrease as a proportion of total C2S from 85.8% in the baseline scenario to 79.8% in scenario 2. Stock movement costs have the highest change, increasing from 5.3% in the baseline scenario to 9% in scenario 2. Terminal handling costs also increase notably from 3.6% in the baseline scenario to 6.2 % in scenario 2. Inventory costs increase from 0.6% in the baseline scenario to 1.2% in scenario 2. In scenario 1 when TopChem Inc. serves all its customers from the South East plant, stock movement to terminal, freight to customer and rail car to terminal costs are higher. In scenario 2, the company needs to bring SKU-1 from Europe to the Gulf Coast terminal and on to other terminals incurring ocean freight, berth costs, inland transportation costs, terminal handling and inventory costs, which significantly increase the total C2S.

Our product flow analysis shows that customer demand is fulfilled differently as we shift supply from the Midwest to the South East and Europe. In scenario 1, the Midwest customer demand is split with 84% dispatched from the South East, a 121% increase, and the South East Canada and North East terminals sharing the balance in scenario 1. These two terminals handle 39% and 56% more SKU-1, respectively. The same is repeated in scenario 2, where the Gulf Coast terminal has an increase of 249% in volume handled as all the supply of 10,434 MT from Europe is first handled at the terminal. Since there is no direct shipment from manufacturing facilities to customers anymore, the South East Canada and North East terminals handle more SKU-1, 58% and 56% higher than they do in the baseline scenario, respectively. Former Midwest customers are jointly served from the Gulf Coast, South East Canada and North East terminals. The West Coast terminal is unaffected in scenario 1 and 2.

Our analysis of C2S by customer reveals that, as the manufacturing facilities change in scenario 1 and 2, the corresponding C2S per metric ton also change, reflecting the changes in transportation, terminal, and manufacturing costs. In scenario 1 where the South East plant fulfills all the demand, the changes result in longer transit distance, causing C2S to increase by between 2% and 20% for customers previously served from the Midwest. In scenario 2 when all SKU-1 is brought from Europe, C2S increases across the board for all customers by between 4%

and 34%. This is because ocean freight and berth costs are charged for product coming from Europe that do not apply in the baseline scenario.

In both scenarios, we see cost increase disparity among different customers. This is because customer location, proximity to terminals or refineries, and the way the customers are served, jointly play a role in determining C2S. The increase in overall C2S and C2S by customer shown in this thesis presents TopChem Inc. with a strategic challenge to keep the SKU-1 business profitable. These costs either have to be reduced by maintaining enough supply capacity in North America or passed on to customers. However, passing these costs on to customers could be very risky in a highly competitive industry. TopChem Inc. could use the results in this thesis as a springboard for further analysis of the SKU-1 business, reformulating agreements with customers and key supply chain partners along the way.

7. Model limitation and Future Work

7.1. Model Limitations

In this thesis, we construct a deterministic model that does not factor in transportation lead time and variability, demand variability, and terminal capacity to give a comprehensive optimization solution. We also make assumptions about how some customers obtain their SKU-1 from TopChem Inc. that may not represent the true state. If these limitations are resolved and included in the model, the optimized solution may differ from what we show in this thesis.

7.2. Assumptions

Customers have a choice to either pick up, or ask TopChem Inc. to deliver SKU-1. In our model, we develop transportation rates for customers that pick up SKU-1 based on regressed data of TopChem Inc.'s transportation rates. We do this so that the model can select the right pick up locations in scenarios 1 and scenario 2. We assume that pick up customers incur the same transportation rates as TopChem Inc. We also assume that these customers continue to pick up SKU-1 in scenarios 1 and 2. These assumptions may not be true. Customers who pick up may have higher rates for the same transportation distance than TopChem Inc. Also, with higher costs in scenarios 1 and 2, customers that pick up SKU-1 may negotiate with TopChem Inc. for the product to be delivered instead of them picking up because TopChem Inc. may have lower transportation rates due to scale economies.

7.3. Transportation lead-time and variability

Transportation lead time and variability affect C2S in two ways. First, lead time increases the pipeline inventory that flows among different nodes. Second, lead time variability increases safety stock as an inventory buffer. Both of these result in added inventory carrying and shrinkage costs. In the SKU-1 business, parcel tank shipment from Gulf Coast to South America is long and highly unpredictable. The transit time averages at 30 days with variation of between 20 and 45 days. This variability and variability in rail and truck transportation would affect the optimal network solution if included in the model.

7.4. Demand variability

Under its current fulfillment process, TopChem Inc. serves its customers on a first-come first-serve basis every month. After customers submit their orders, they cannot increase order quantity unless other customers reduce or cancel orders. There is no mechanism to track customer service level or lost sales. Thus, the C2S generated by the model may be underestimated without taking lost sales and unattained customer service level into consideration.

7.5. Terminal capacity and Inventory Level

Terminal constraint is not included in our model for two reasons. First, TopChem Inc. serves its customers on a monthly basis. Since its current terminal capacities are much bigger than the monthly demand from the terminals, capacity is not a constraint. Second, an inventory policy needs to be defined to decide appropriate terminal capacities. TopChem Inc. takes a weighted average approach to recording inventory carrying cost. This approach does not differentiate and segregate pipeline inventory from cycle stock. In addition, safety stock and associated cost are not included in the model. As a result, the model result does not incorporate all costs associated with C2S. In the future, these costs are likely to gain relevance as terminal capacity may be an issue if the company decides to ship less frequently or adjust its terminal capacities.

7.6. Future work

The network optimization model that we build is a starting point to evaluate how shifts in supply and demand affect the total cost to serve SKU-1 customers. However, to address the limitations mentioned in the previous section, we propose that the work in this thesis be expanded by looking at the following:

1. We show in the scenario analysis that C2S increases at TopChem Inc. as the Midwest manufacturing capacity is taken out of the network, leaving only South East and Europe. Given the competitive nature of the business, the company may not be able to pass along the higher costs to its customers. The company will have to improve SKU-1 costs to remain profitable. Some things that the company could take into consideration in more research include using ABC analysis to rationalize its customers and service level, optimizing order fulfillment frequency, and using another terminal such as the one in the North East as an entry point for SKU-1 shipped from Europe.
2. TopChem Inc. should consider a well-defined inventory policy. With its current supply chain setup, we feel that a monthly inventory review under (R, S) is appropriate for this product. With this policy, each SKU-1 order to the refineries will add up to S every R review time periods, where S is defined to include the demand over the review period, delivery lead time, and the safety stock. An appropriate customer service level could also be incorporated. This inventory policy will help quantify pipeline inventory carrying cost, safety stock and lost sales. As the company gradually brings in more products from Europe through the Gulf Coast terminal, a multi-echelon inventory system that the Gulf Coast terminal would use, as a distribution point for other terminals, can be further studied.
3. TopChem Inc. should rationalize its terminal capacities, incorporating demand variability and a defined inventory policy. This will allow the company to determine the right terminal capacities and locations to serve its customers. Terminal contracts can then be renegotiated to reflect the storage needs and costs.

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