From Plant to Dealer: Improving Route Optimization for Outbound Vehicle Distribution at an Automobile Manufacturer

by

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B.S. Architecture, Massachusetts Institute of Technology, 2008

Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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Abstract

With rising fuel costs and increasing rates among specialized shipping carriers, cost mitigation in outbound distribution is increasingly important for automobile manufacturers. Many manufacturers have turned to specialized, licensed supply chain software to optimize their distribution network to determine the appropriate path for each product from factory to dealer. While these software programs include robust algorithms for optimizing the network, they are only as strong as the user inputs. To gain maximum value from supply chain software, automotive companies must fully understand the structure of their networks, their costs, and their constraints to ensure that the model is all-inclusive.

This paper attempts to understand the distribution model used at Nissan North America by formulating the model algebraically with a linear program. With insights to the model design, we uncover several opportunities for improvement. Specifically, we create a more inclusive objective function by ensuring that all relevant costs are captured so that the model optimizes the "total landed cost." We also highlight several opportunities for increased model flexibility in areas where the model is over constrained -- both in its mathematical constraints and in its structural design. With increased flexibility, supply chain software has more alternative paths in the network to choose from, increasing the opportunity for the program to find a lower cost solution. Lastly, we stress the importance of using the software for scenario analysis to create a more responsive supply chain. When implemented, the improvements presented in this paper yield a cost savings of over $10 million. The principles of the model improvements in this thesis can be applied to distribution optimization in any industry.

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On a personal level, immediately before this project was set to begin in June 2011, I was diagnosed with Diffuse Large B-Cell Lymphoma. My project was delayed until January 2012 while I underwent chemotherapy at Sloan Kettering Memorial Cancer Center in New York. I want to thank the LGO program, specifically Don Rosenfield and Patty Eames, for adjusting the schedule of my curriculum to allow me to graduate only three months late despite this setback. I also would like to thank Nissan for allowing me to delay the start of my internship without changing the scope of the project.

Additionally, I am grateful to Dr. Ariela Noy, my medical oncologist at Sloan Kettering, for curing me, and allowing me to return to my normal life. I also owe thanks to my family, friends, and classmates, for being supportive throughout my illness and finding ways to keep my spirits up during a very trying time.

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Note on Proprietary Information

To protect proprietary information, the data presented throughout this thesis has been altered and does not represent the actual values used by Nissan North America, Inc. The dollar values have been disguised to protect competitive information. This includes all transportation rates, product values, and costs presented throughout the paper. Additionally, Nissan North America works with a number of third part logistics providers to handle different portions of its logistics. To protect privacy, the specific 3PLs will be referred to in this paper as Company A.

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PART 1: Introduction

1.1 Project Purpose

With a large dispersion of dealers, it is critical that automobile manufacturers distribute their finished products at low cost. Manufacturers can achieve cost effectiveness in their distribution network through optimization of vehicle routing from the factories to the dealers. Many manufacturers use specialized supply chain software to continually optimize their distribution network. The primary purpose of this paper is to identify areas for improvement within the outbound vehicle distribution routing model in an automotive manufacturer. In particular, the paper focuses on minimizing the "total landed cost" of distribution, while increasing flexibility in the logistics network, using Nissan Motor Company's North American market as a case study.

Nissan Motor Company currently outsources all of its outbound vehicle logistics for the North American market to a third party logistics provider, Company A. Company A handles all aspects of distribution of products from each factory or port to each dealer in the United States. It provides both operational and strategic support: it processes and accessorizes vehicles, works with carriers to ensure proper shipments, and conducts carrier contract negotiations on behalf of Nissan North America, henceforth referred to as NNA. In addition, Company A owns the routing optimization function and optimizes the distribution network for NNA. NNA oversees Company A and approves any changes or exceptions to the current routing.

Company A uses a software called i2 Supply Chain Strategist to optimize outbound vehicle routing in North America. NNA has limited visibility into the inputs to the model, since Company A handles it exclusively. The goal of this project is to understand the inputs and constraints in the model, to find opportunities for improvement, and to standardize the process for route optimization through the use of the i2 tool. In particular, this paper will focus on understanding the current model and its formulation and identifying three particular areas of improvement:

1. Increasing flexibility in the model
2. Including transit inventory costs in the model
3. Using the model proactively rather than reactively

This paper will use case studies to analyze these three areas. Each case study will provide examples within NNA's distribution network where NNA could yield cost savings by implementing the strategy.

1.2 Thesis Overview

The research for this thesis was conducted in collaboration with NNA employees, Company A employees, and MIT faculty from January 2012 to June 2012. The thesis is divided into six sections and is organized as follows:

Part 1 provides the motivation for the project and an overview of the contents of this thesis.

Part 2 provides background information, including an overview of NNA, and an overview of the third party logistics provider, Company A, the history behind logistics outsourcing at NNA, and an overview of how vehicle distribution is conducted at the Company.

Part 3 reviews current literature on optimizing distribution routing and the drivers of total landed cost.

Part 4 describes the current optimization of vehicle routing at NNA. Included in this section is a description of the current optimized routing, a description of the software used to optimize the routing, and a description of the model's objectives, constraints and output.

Part 5 addresses the potential improvements in the distribution routing. The section quantifies the cost reductions for each improvement and weighs the improvement against its ease of implementation.

Part 6 concludes the paper by describing additional steps NNA can take to reduce its total landed cost and increase flexibility in its distribution network.

PART 2: Background

2.1 Company Overview

Nissan Motor Co. is a publically traded automotive manufacturer headquartered in Yokahama, Japan. It manufactures and sells automotive products, industrial machinery, and marine equipment primarily in Japan, North America, and Europe. It offers passenger cars, trucks, buses, forklifts, light commercial vehicles, power trains, and parts [3]. In 2011, Nissan's revenues were 8,821,462 million Japanese yen, or $114,713 million US dollars[1].

Nissan markets its vehicles to the U.S. market under two brand names: the non-luxury Nissan line and the luxury Infiniti line. This paper will focus on the manufacturing and distribution of passenger cars and trucks under both the Nissan and Infiniti brands, which are the core of Nissan's business. NNA's vehicles are currently manufactured in Japan, Mexico and the United States.

Nissan North America, Inc. operates as a subsidiary of Nissan Motor Co. to oversee United States manufacturing, design and development, sales, marketing, and distribution of vehicles to the North American market. NNA, is headquartered in Franklin, TN, with manufacturing facilities in Smyrna, TN and Canton, MS. Figure 1 displays a list of Nissan and Infiniti products marketed in North America, along with their production source (Japan, Mexico, Smyrna, or Canton). NNA currently enjoys a 8.2% market share in total automobile sales in North America from April 2011 to March 2012.

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[1] Exchange rate based on that in January 2012.

Figure 1: List of Nissan and Infiniti Products by Manufacturing Site[2]

Japan (NML)	Mexico (NMEX)	Smyrna (NNAS)	Canton (NNAC)
Cube GT-R Infiniti EX Infiniti FX Infiniti G-series Infiniti M-series Infiniti QX Juke Leaf Murano Quest Rogue Z	Sentra Versa	Altima Frontier Infiniti JX Leaf Maxima Pathfinder Xterra	Altima Armada Titan

Culturally, Nissan is a cost conscious Company, a mindset passed down from its CEO, Carlos Ghosn, who is well known for "rescuing" Nissan from its troubles in the late 1990s [13]. Ghosn states in his autobiography, *Shift, Inside Nissan's Historic Revival,* "From the beginning, I knew that an important component of the plan would be cost reduction. Another would be the sale of unessential assets [11]." This focus on cost savings led to Nissan outsourcing logistics in North America.

2.2 Overview of Third Party Logistics

Third party logistics, or 3PL, is the use of an outside Company to perform all or part of a Company's materials management and/or their product distribution functions [18]. 3PL services can include functions such as inventory management, warehousing, procurement, transportation systems administration, information systems, materials sub-assembly, contract manufacturing, kitting and import and export assistance. Third party logistics is about "getting the right products

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[2] While there are several plants in Japan and two in Mexico, the Japanese and Mexican sources are each treated as a single production source for purposes of North American Distribution.

to the right place at the right time, and at the right cost, all with the help of an outsider [20]." NNA currently employs a 3PL provider, Company A, for the entirety of its outbound vehicle distribution.

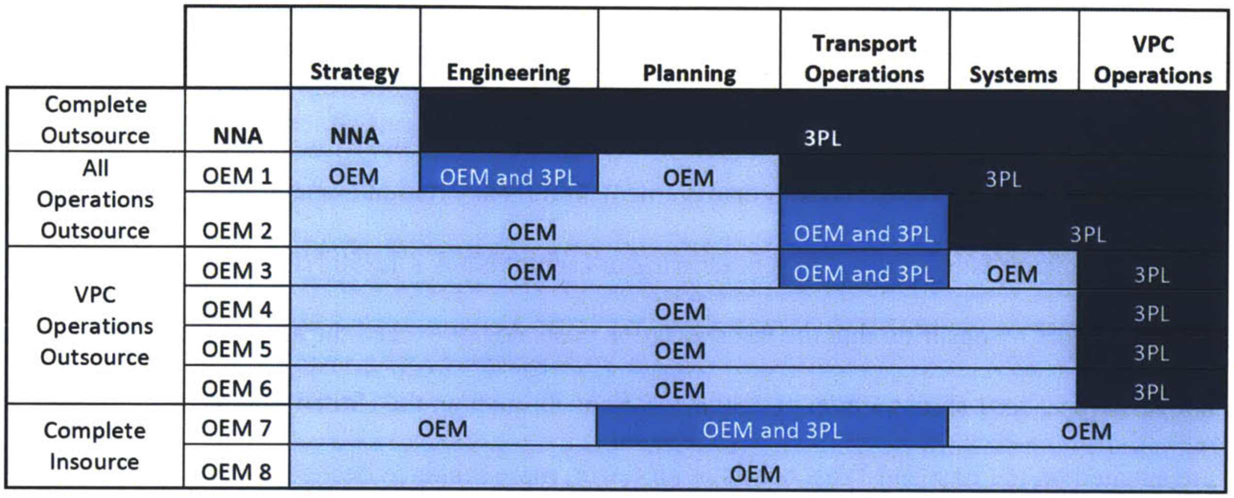
Company A provides outbound vehicle logistics services for the automakers and heavy vehicle and equipment manufacturers. It offers supply chain management, ocean transportation, inland distribution, and terminal services, as well as technical services, such as accessory fittings, repairs, storage management, vehicle preparation, and receipt and dispatch[3].

Before 2004, NNA managed its own logistics through a wholly owned subsidiary, Distribution and Auto Service, Inc. (DAS), which provided vehicle distribution in the United States. NNA's Canadian and Mexican regions also managed their own logistics internally. In 2004, NNA sold DAS to Company A. Company A received a contract to perform all vehicle processing, carrier contract negotiations, and logistics planning on behalf of NNA. As with all outsourcing, NNA sold DAS in an effort to create a cost advantage through economies of scale by consolidating volume with an external provider. However, the sale of DAS did not help avoid rate increases in the industry.

There are four basic strategies for outbound logistics outsourcing in the automotive industry, as shown in Figure 2. The first strategy is a complete outsourcing of outbound logistics, including engineering, planning, transport operations, systems, and VPC operations. In this strategy, the only functions that are insourced are the logistics strategy and oversight of the 3PL. NNA is the only OEM to employ this strategy for the North American market. The second strategy is to outsource all operations and systems but to insource the strategy and planning phases. The third strategy is to outsource only the VPC operations. Systems and transport operations are insourced. Most OEMs use this strategy for their outbound logistics in North

America. The fourth strategy is to completely insource all aspects of outbound logistics. In this strategy, a 3PL may be used for their logistics knowledge, but the OEM will have control over all aspects of the process. The decision by an OEMs on the scope of outsourcing depends on the core competencies of the OEM, its source of competitive advantage, and its willingness to give up control.

Figure 2: Scope of 3PL Outsourcing in Industry



		Strategy	Engineering	Planning	Transport Operations	Systems	VPC Operations
Complete Outsource	NNA	NNA	3PL				
All Operations Outsource	OEM 1	OEM	OEM and 3PL	OEM	3PL		
	OEM 2	OEM			OEM and 3PL	3PL	
VPC Operations Outsource	OEM 3	OEM			OEM and 3PL	OEM	3PL
	OEM 4	OEM					3PL
	OEM 5	OEM					3PL
	OEM 6	OEM					3PL
Complete Insource	OEM 7	OEM		OEM and 3PL		OEM	
	OEM 8	OEM					

In his book, *Designing and Managing the Supply Chain,* MIT Civil Engineering Professor David Simchi-Levi enumerates the advantages and disadvantages of using a 3PL [18].

<u>*Advantages of a 3PL*</u>

- Outsourcing logistics allows the Company to concentrate on its core strengths.
- 3PL providers tend to update their technology and systems as technology advances more frequently than the Company has the resources to do on its own.
- The 3PL exhibits economies of scale, which allow for reduced costs and a more diverse set of geographic locations and service offerings.

Disadvantages of a 3PL

- The hiring Company loses control of the distribution function by outsourcing to a 3PL.
- Sometimes the hiring Company actually has greater expertise in some of the logistics functions than the 3PL.

2.3 Vehicle Distribution at Company

The Vehicle Logistics group at NNA manages North American vehicle distribution at Nissan. Its role is to manage the shipment of damage-free finished vehicles using the most efficient and cost effective methods. The team also oversees the daily operation of Company A in its processing of vehicles, storage management, and transportation management. The goal of Vehicle Logistics is to satisfy 100% of demand at each of NNA's 1,250 Nissan dealers and 250 Infiniti dealers by ensuring that the transportation costs do not exceed the annual logistics budget. Appendix 1 shows a map of dealer locations throughout the United States. Most dealers are situated on the East and West coasts, with fewer, more scattered dealers in the Central and Midwest regions of the United States. In addition to demand at dealers, ten percent of NNA's volume is considered "fleet." Fleet vehicles are sold to rental car companies and are usually drop shipped to the rental location.

NNA transports vehicles using three modes of transportation: ocean shippers, rail carriers, and trucking carriers. Company A negotiates and holds the rail and truck contracts with each of the carriers, while Nissan negotiates and holds the contracts for ocean carriers.

Ocean shipping is used to transport vehicles from Japan to North America and from Mexico to the East coast of the United States. While ocean shipping is the cheapest form of transportation, it is also the slowest, taking several weeks to cross the Pacific. Because of the long lead times, vehicles are often shipped from Japan to the United States before they have been allocated to specific dealers[3].

Railroads transport vehicles long distances throughout North America on specialized railcars designed to carry automotive products. Railcars are either tri-level, bi-level, or automax (see images in Appendix 2). Tri-level railcars hold 15 cars, but can only fit sedans. Bi-level railcars fit 10 cars and are used for taller vehicles such as trucks and SUVs. Automax railcars are used to transport High Roof Light Commercial Vehicles (LCVs). The railroads own the autorack portion of the railcars and TTX, a railcar supply management company owns the flat card portion. These portions are labeled in the images in Appendix 2. NNA is limited to the capacity the railroads have allocated for them. There are eight key railroad carriers in North America, each of which serves its region exclusively[4]. The railroads, therefore, enjoy power when negotiating contracts due to limited competition and fixed locations of facilities and tracks.

Figure 3: List of Key North American Railroads

Railroad	Region
CSX	East
Norfolk Southern	East
BNSF	Northwest, Southwest, Midwest
Union Pacific	Southwest and Midwest
Canadian National	Canada
Canadian Pacific	Canada
Ferromex	Mexico
KCSM	Mexico and East

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[3] Although vehicles may not be allocated to a dealer, they are allocated to a sales region, which dictates the port assignment.

[4] As of 2012 Nissan only contracts with CSX for the East, with Canadian National for Canada, and with Ferromex for Mexico.

Rail contracts are structured as a rate per rail car for a given rail leg. For instance, the contract will specify how much it will cost to transport a single railcar from the Smyrna plant to Chicago, IL. Rates for bi-level railcars are more expensive than those for tri-level railcars. Because there is a smaller load on the bi-level railcars, the rate per vehicle is even more expensive on the bi-level railcars. Industry benchmarking shows that most rail contracts generally last five to seven years and include annual escalators for the duration of the contract based on economics.

Truck carriers transport vehicles directly from the plants to dealers in the case of dealers in close proximity to the plant, and from the ports and railheads in the case of dealers more distant from the plants. Like railroads, truck carriers also operate regionally, with each truck carrier only servicing a single state. However, unlike railroads, the automotive trucking market is more competitive with two or three carriers per state. Once the trucks pick up the vehicles from the plant, port, or railhead, the vehicles are considered "wholesaled" and are transferred from NNA inventory to dealer inventory. Truck carriers are responsible for how they route their trucks from the plant, port, or railhead to the dealers.

Truck carriers transport vehicles directly from the plants to dealers in the case of dealers in close proximity to the plant, and from the ports and railheads in the case of dealers more distant from the plants. Like railroads, truck carriers also operate regionally, with each truck carrier only servicing a select portion of the region. However, unlike railroads, the automotive trucking market is more competitive with multiple carriers positioned regionally. Truck carriers are responsible for how they route their trucks from the plant, port, or railhead to the dealers.

Trucking contracts are structured with fixed and variable pricing. For the variable portion, the rates are typically established on per mile per vehicle basis. For instance, a trucking carrier in New York will specify how much it would cost NNA to transport one vehicle one mile. Since the costs are per vehicle rather than per truck, it is the responsibility of the trucking carrier to ensure high load factors.

Both truck and rail contracts also include a program for variability in fuel, known as the fuel surcharge. The fuel surcharge (FSC) program is very consistent across the industry. There is an established fuel peg with "surcharges" applied to anything that exceeds this peg. Different companies strategies and the time when the contract was signed dictates where the peg was set. In addition, some companies have moved to a mileage based FSC programs to gain more transparency to the fuel costs. NNA currently utilizes a mixture of FSC programs but will move in the direction of a mileage-based program.

PART 3: Literature Review

Every manufacturer faces the task of discovering the least costly method of distributing its products to its customers. There has been a plethora of research in the area of network optimization for the purposes of minimizing costs in distribution systems. The models discussed in the literature provide the backbone for the design and algorithms embedded in the software used by companies to optimize their networks.

This chapter reviews the current literature on distribution models. Specifically, it will describe how the model is constructed algebraically, will give an overview of algorithms used to solve the problems, and will highlight what costs should be included in the model design so that a Company is truly minimizing its "total landed cost."

3.1 Model Design and Algorithms

Solutions to network design problems seek to minimize costs through optimized placement of facilities and routing of products. The model is generally constructed in the form of an integer linear program. Geoffrion and Graves, 1974, were among the firsts to develop a formulation and solution for the problem, using an algorithm known as "Bender's decomposition [9]." The problem is formulated through a series of subscripted variables, an objective function, and standard constraints. The following formulation, developed by Geoffrion and Graves, provides the framework for all network distribution models today.

Variable definitions

Figure 4: Variable Definitions in Geoffrion and Graves Distribution Model

Variable	Definition
i	Index for commodities, or products.
j	Index for manufacturing plants.
k	Index for distribution centers.
l	Index for customer demand zones.
S_{ij}	Supply for commodity i at plant j.
D_{il}	Demand for commodity i at customer l.
V_k, $V^{\wedge}_k$	Minimum and maximum throughput at distribution center k.
f_k	Fixed portion of the annual possession and operating costs for a distribution center.
v_k	Variable unit cost of throughput through a distribution center. This would be the handling cost.
c_{ijkl}	Variable transportation cost of producing and shipping commodity i from plant j through DC k to customer l.
x_{ijkl}	The variable denoting the volume of commodity i flowing from plant j through DC k to customer l. **These are the decision variables in the formulation.**
y_{kl}	A binary variable denoting whether DC k serves customer l.
z_k	A binary variable denoting whether a DC is active at site k.

Objective Function

The objective function seeks to minimize a combination of variable transportation cost, fixed facility costs, and variable handing costs. Transportation costs could include any variable costs associated with traveling along a particular lane including rates paid to carriers, fuel, inventory costs, and costs of repairing damages along the lane.

$$\text{Minimize } x \geq 0; y, z = [0,1] \;\; \sum_{ijkl} c_{ijkl}\, x_{ijkl} + \sum_k [f_k z_k + v_k \sum_{il} D_{il} y_{kl}]$$

Equation 1: Objective Function by Geoffrion and Graves.

Model Constraints

There are several standard constraints for the network distribution problem, which bound the problem by supply, demand and capacity.

Figure 5: Constraints in Geoffrion and Graves Distribution Model

Constraint	Description
$\sum_{kl} x_{ijkl} \leq S_{ij}$ for all ij	The total flow from a plant must be less than or equal to the supply at that plant. **Equation 2: Supply Constraint in Geoffrion and Graves.**
$\sum_{j} x_{ijkl} = D_{il} y_{kl}$ for all ikl	The total flow from all plants through a warehouse must satisfy demand for that commodity at a particular customer. **Equation 3: Demand Constraint in Geoffrion and Graves.**
$\sum_{k} y_{kl} = 1$ for all l	Each customer must be served by one warehouse for all of its products.[5] **Equation 4: Single Path Constraint in Geoffrion and Graves.**
$V_k z_k \leq \sum_{il} D_{il} y_{kl} \leq \hat{V}_k z_k$	The total flow through distribution center must fit within the minimum and maximum for that facility. **Equation 5: Capacity and Volume Constraint in Geoffrion and Graves.**
Linear configuration constraints on y or z.	This is a miscellaneous constraint that provides flexibility for a Company to incorporate many complexities unique to its business. **Equation 6: Miscellaneous Constraint in Geoffrion and Graves.**

Model Solution

Multicommodity network problems are often too large and complex to be solved through simple algorithms. There have been many algorithms developed to break down the problem into several smaller ones before optimizing globally. These algorithms are programmed behind the scenes on the backend of supply chain optimization software used by companies today.

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[5] This is a constraint for many companies whose accounting and marketing structures only allow for serving each customer from a single distribution center [9].

Geoffrion and Graves use a technique called "Bender's Decomposition" that breaks down the problem into as many independent transportation sub-problems as there are commodities [9]. The algorithm was developed in 1962 by J.F. Benders to solve complex linear programs that have a "block structure [2]." Applying the method solves for each commodity independently by ignoring y and z, the variables that link the commodities. The algorithm ignores the fixed facility costs, capacity and volume constraints, and single path per customer constraint. Once the optimization is solved for each commodity, the algorithm will solve globally to incorporate the linking constraints.

Erlenkotter, 1976, uses a "branch and bound" technique to solve a similar network design problem that concentrates more on facility locations than on routing. The "branch and bound" algorithm was developed by A. H. Land and A. G. Doig in 1960 and involves a systematic enumeration of all possible solutions [12]. Large sets of solutions are discarded as non-optimal by using upper and lower estimated bounds on the optimized value of the objective function.

Bender's decomposition and branch and bound algorithms are too complex to solve by hand and are solved using optimization software. The first optimization packages were developed in the late 1950's, and were able to solve simple linear programs [17]. In the early 1970's, software was developed to solve mixed integer problems such as the one described above by Geoffrion and Graves [17]. There are three key types of optimization software, discussed by Jeremy Shapiro, former professor of Sloan School of Management in his book, *Modeling the Supply Chain* [17]:

1) *Optimizers:* Optimizers are small software packages containing numerical algorithms that analyze a given matrix representation of an ILP or MIP to produce an optimal solution.

2) *Algebraic modeling development kits:* The algebraic modeling development kits include optimizers, but also an algebraic modeling language interpreter. The interpreter allows the user to specify the mathematical formulation of the supply chain model, using algebraic syntax (as represented above by Geoffrion and Graves). The interpreter will pull the data from a specified database and formulate the matrix representation of the problem on its own. Although this can be easier for the user, it also will have slower runtimes and will need more vigilance from the user to ensure that the data is properly linked to the algebraic formulation.
3) *Spreadsheet optimizers:* Spreadsheet optimizers are add-in optimization software to spreadsheet programs such as Microsoft Excel or Access. They allow the user to create and optimize the program, all from within the spreadsheet. These optimizers are limited by the memory and power in the spreadsheet program itself. Therefore, these optimizers should only be used for small problems.

Most commercial supply chain software are combinations of optimizers and algebraic modeling development kits. The data is represented in a matrix form, with limited ability to construct an algebraic formulation. However, there are easy to use graphical user interfaces, which break down the data with links between the data tables.

3.2 Total Landed Cost

The objective function in Equation 1 minimizes the sum of variable and fixed costs. To truly optimize the network, the Company must understand the entire scope of what is included in the variable cost, so that it minimizes its "total landed cost," and not simply its transportation freight cost. There has been vast research regarding what is included in "total landed cost" in a logistics network. According to an article published by Infosys on Landed Cost Optimization, a model should include transportation costs, handling costs, inventory holding costs, insurance costs, expected damage costs, import and export charges, tariff charges by country, storage costs, currency exchange costs, freight term impact on cost, and supplier incentives or discounts [10].

In his master's thesis, Brian Feller, 2008 graduate of Leaders for Global Operations, divided the cost components of landed cost into four categories: Logistics, Trade, Inventory, Purchasing, and Finance [8]. Using these categories, cost inputs would be categorized as shown in **Figure 6**.

Figure 6: Total Landed Cost Inputs

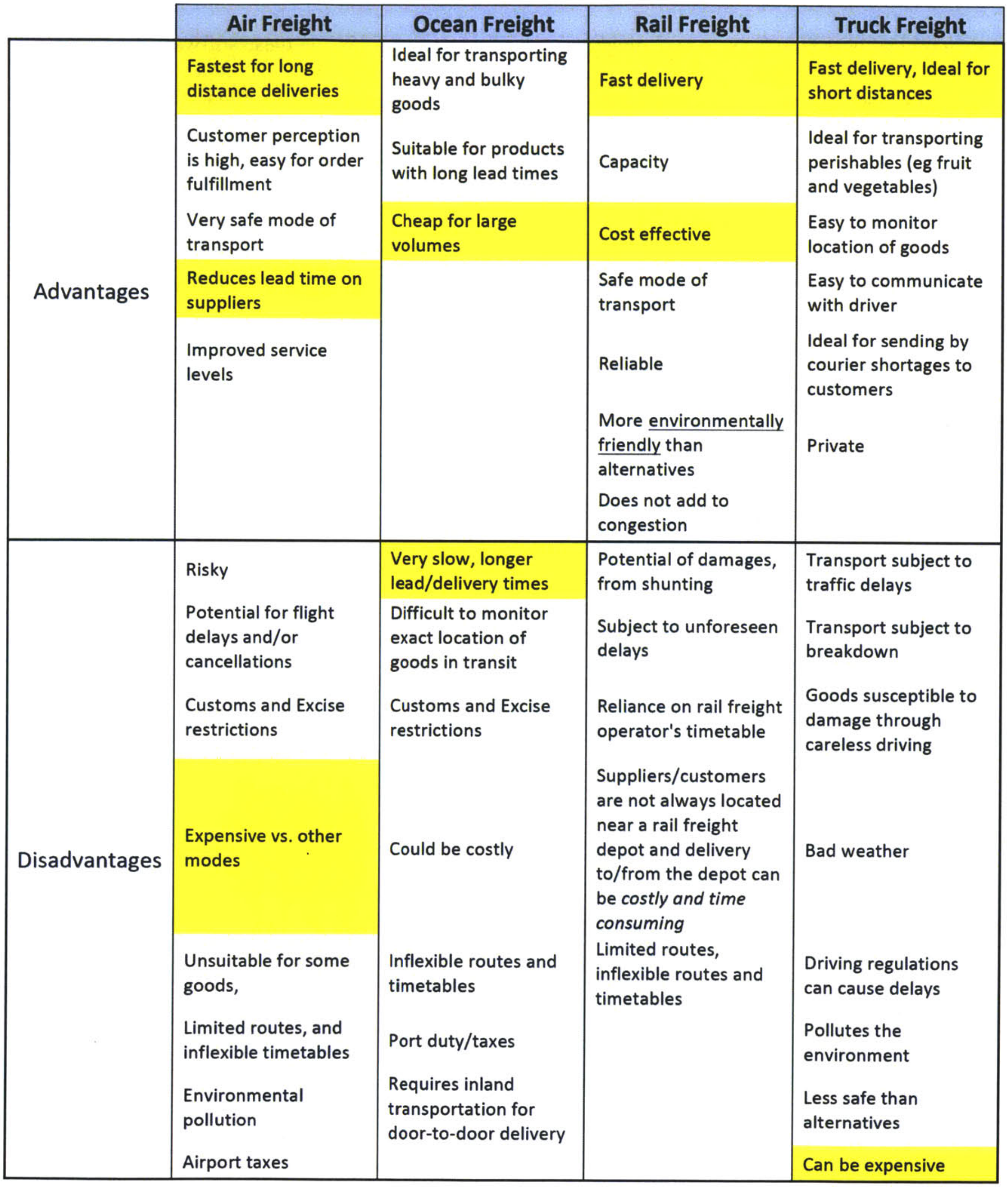
Logistics	Trade Compliance	Inventory	Purchasing	Finance
Freight	Duties	Average Inventory	Material	Payment Terms
Fuel Surcharge	Tariffs	Safety Stock	Packaging	Volume Discounts
Accessorial	Customs Fees	Transit Inventory		
Hazmat		Warehousing		
Damages				

When optimizing the distribution network, there are tradeoffs between each of these cost components. For instance, it is often the case that decreased packaging, warehousing, and freight costs could increase the probability of damages, thereby increasing the cost of repairs. One particularly important tradeoff that is often discussed in the literature is that of freight costs and inventory costs. This tradeoff exists when deciding the number of warehouses and when choosing a transportation mode (e.g. air, ocean, rail, truck).

In addition to optimizing routing, network optimization models optimize the number and location of warehouses. Increasing the number of active warehouses typically yields an increase in service level by reducing transit time to the customer, an increase in inventory costs due to increased safety stock levels from disaggregation of demand variability, and a reduction in outbound transportation costs due to closer proximity to customers [18]. Das and Tyagi discuss this tradeoff extensively in the context of centralized versus decentralized inventory warehousing [5]. A centralized system includes few warehouse locations and enjoys reduced factory to warehouse transportation costs, improved inventory management, reduced safety stock, and more leverage in negotiating transportation services [5]. A decentralized system has many warehouses and enjoys high service levels, reduced warehouse to customer transportation costs, and a better availability of stock leading to increased sales [5].

The tradeoff also exists when considering transportation mode. A faster mode of transportation will increase service level by increasing speed of delivery to the customer, will decrease inventory costs for both safety stock and transit inventory by reducing the lead time, but will often result in higher freight costs. For instance, air and truck freight costs are higher than ocean and rail costs, but the speed of delivery is quicker. On their website, NEFAB, and global logistics packaging company, discuss the advantages and disadvantages of various modes of transportation, siting the cost/speed tradeoff, shown in **Figure 7** [14]. Chan and Simchi-Levi deal with the tradeoff between transportation costs and inventory costs, by simultaneously solving for the optimum inventory control policy and distribution routing [4].

Figure 7: NEFAB Advantages and Disadvantages of Various Transportation Modes



	Air Freight	Ocean Freight	Rail Freight	Truck Freight
Advantages	Fastest for long distance deliveries	Ideal for transporting heavy and bulky goods	Fast delivery	Fast delivery, Ideal for short distances
	Customer perception is high, easy for order fulfillment	Suitable for products with long lead times	Capacity	Ideal for transporting perishables (eg fruit and vegetables)
	Very safe mode of transport	Cheap for large volumes	Cost effective	Easy to monitor location of goods
	Reduces lead time on suppliers		Safe mode of transport	Easy to communicate with driver
	Improved service levels		Reliable	Ideal for sending by courier shortages to customers
			More environmentally friendly than alternatives	Private
			Does not add to congestion	
Disadvantages	Risky	Very slow, longer lead/delivery times	Potential of damages, from shunting	Transport subject to traffic delays
	Potential for flight delays and/or cancellations	Difficult to monitor exact location of goods in transit	Subject to unforeseen delays	Transport subject to breakdown
	Customs and Excise restrictions	Customs and Excise restrictions	Reliance on rail freight operator's timetable	Goods susceptible to damage through careless driving
	Expensive vs. other modes	Could be costly	Suppliers/customers are not always located near a rail freight depot and delivery to/from the depot can be *costly and time consuming*	Bad weather
	Unsuitable for some goods,	Inflexible routes and timetables	Limited routes, inflexible routes and timetables	Driving regulations can cause delays
	Limited routes, and inflexible timetables	Port duty/taxes		Pollutes the environment
	Environmental pollution	Requires inland transportation for door-to-door delivery		Less safe than alternatives
	Airport taxes			Can be expensive

3.3 Literature Review Summary

Many companies, including NNA, rely on supply chain software with user-friendly graphical user interfaces to optimize their logistics networks. While these softwares have robust capabilities, the model formulation is often behind the scenes and not visible to the user. Understanding the models and algorithms behind the software is important to truly understanding how a Company is optimizing its network.

The current literature on logistics network optimization provides a good basis for understanding NNA's distribution network. Section 4.2 will apply Geoffrion and Graves' ILP formulation to NNA's network to better understand the current model constraints. Section 5.2 will expand the costs included in the model through the inclusion of inventory costs to ensure that NNA is truly optimizing its "total landed cost."

PART 4: Current Vehicle Routing Optimization

4.1 Current Distribution Routing

NNA has unique distribution systems for products from each of its seven[6] production sources. The routing is based on a limited number of ports and railheads that Company A has contracted for use. Depending on the production source, NNA will either truck to the dealers directly from the ports or plants or will rail product to another railhead before trucking the products to the dealers. The distribution network for each production source is described briefly below, with network distribution maps in the Appendix.

Products from Japan are sent by ocean over the Pacific (see Appendix 3). The ocean vessel will stop in Wilmington, CA, outside of Los Angeles, to unload products destined for the West, Central, and Midwest regions. Products destined for California, Arizona, Utah, and Nevada are trucked directly to the dealers from the port. Products going to the Pacific Northwest are sent via rail to Portland. Products destined for the Midwest and Central regions will be railed to railheads in Chicago, Denver, Albuquerque, and Mesquite. Products headed to the East coast will continue by ocean through the Panama Canal to ports in Jacksonville, FL, Newport News, VA, and Port Elizabeth, NJ. Vehicles are then trucked to these East coast dealers directly from the ports.

Products from Smyrna and Canton are largely distributed using rail (see Appendix 4 and Appendix 5). Because Smyrna is located on the CSX rail line, products shipped east are railed directly from Smyrna. Products shipped west must stop in Gavin, TN, a large interchange for many railroads, to be transferred to the appropriate railroad. Canton is located on the Canadian

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[6] There are three production sites in Japan (Kyushu, Oppama, and Tochigi), two in Mexico (Aguascalientes and Cuernavaca), and two in the United States (Canton and Smyrna).

National rail line. Therefore, all products bound for Canada are railed directly from Canton to the Canadian railheads. Products bound for U.S. dealers are sent to Gavin to be transferred to the appropriate rail line. For both the Smyrna and Canton plants, products that are destined for dealers in the Southeast and Midwest regions are trucked directly from the plants.

Mexican products from the plant in Aguascalientes are railed to either the U.S. border or to the port of Veracruz (see Appendix 6). Mexican products from the plant in Cuernavaca are either trucked to Toluca or trucked to Veracruz. Products railed to the border cross at El Paso, TX for west bound products, at Laredo, TX for midwest bound products, or Eagle Pass, TX for east bound products. Products destined for the east coast (with the exception of southern Florida and New England, which are shipped via rail through Eagle Pass), are ocean shipped from the port of Veracruz to either Jacksonville, FL or Baltimore, MD and are then trucked from the ports directly to the dealers.

4.2 Understanding the Model Inputs

4.2.1 i2 Supply Chain Strategist

Company A uses software called i2 Supply Chain Strategist to optimize NNA's vehicle distribution. i2 Supply Chain Strategist (SCS) is a network modeling and optimization tool that can be used strategically by supporting scenario planning and analysis across the entire supply chain. Using the software, a Company can model product flows and associated costs, capacities, and service constraints. Although the program has the capability to analyze the entire range of supply chain functions, from raw materials through production, distribution, and consumption, a Company can use the software to focus only on individual supply chain segments such as component sourcing or customer distribution. Through quick and easy optimization, SCS allows managers to understand the total cost, profit, and service tradeoffs that exist between alternative network scenarios. **Figure 8** lists all of the i2 capabilities and describes what questions managers can answer using the software.

Figure 8: i2 Capabilities

Capability	Description
Site location	Where should the Company locate its plants, distribution facilities or other logistics facilities?
Facility missions	What products and processes should the Company locate within each facility?
Product sourcing	What products should the Company source from which product source options?
Inventory deployment strategy	Where should the Company stock products and what should its inventory levels be?
Transportation strategy	What modes and lanes should the Company use to move products throughout the network?
Service territory alignment	Which customers should the Company service from which facilities?
Supply chain operations	What product quantities, by facility and by process, should be produced and stored in each period to support customer demands?
Supply chain profitability	What products should the Company sell and which customers should the Company serve to maximize its profit contribution?

NNA and Company A use the i2 software only for transportation strategy, that is to determine the optimum transportation lanes to distribute finished vehicles from their factories to their North American dealers. i2 will choose from various shipping, rail, and trucking lanes to serve each dealer and production source combination. Company A runs i2 on a quarterly basis, with interim runs at the time of a carrier contract change.

4.2.2 Model Objective

i2 optimizes to maximize profit for the Company, using a generic objective function of:

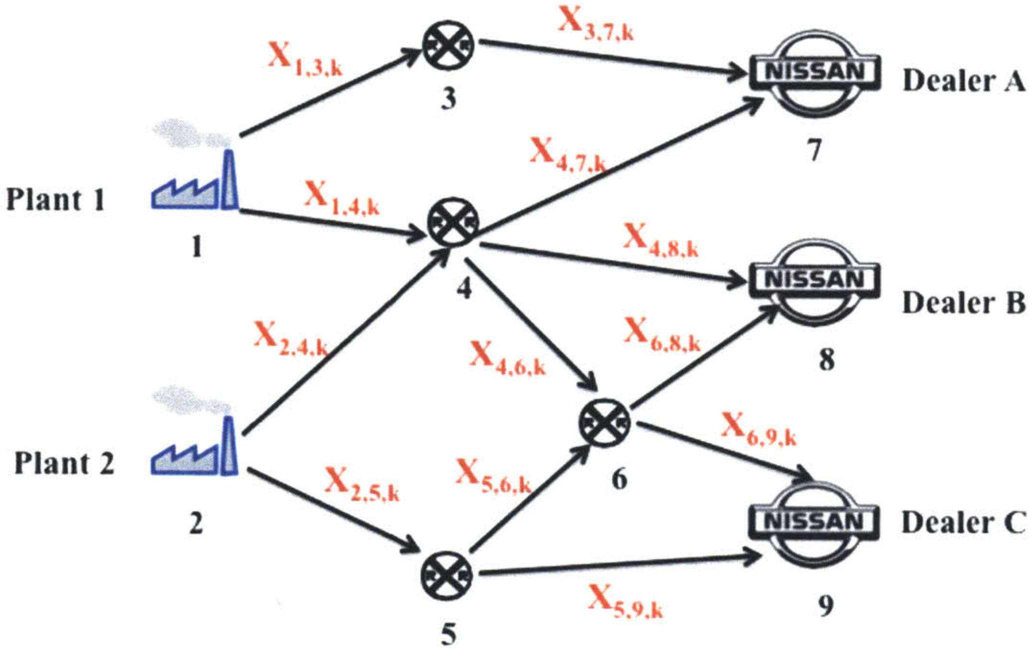
$$Maximize\ (Profit) = Revenue - Cost$$

Equation 7: Generic Objective Function

There are no revenue data in NNA's model, and therefore, i2 will maximize profit simply by minimizing costs. i2 has the capacity to consider all costs including fixed facility operating costs, fixed costs to manufacture a product at a facility, fixed inventory costs, variable manufacturing costs, variable handling costs at facilities, variable storage costs, variable transportation costs both between facilities and to service the customers, and variable inventory holding costs. Because Company A and NNA only use the software for transportation routing and not for production planning or facility locating, they only consider variable costs. Under the current model design, only variable transportation costs of each origin-destination link are included. Transportation costs are represented as a "cost per unit," which includes both the contracted transportation rate and the fuel surcharge for a given product to travel on a particular origin-destination leg.

Because of some binary constraints such the single path constraints (**Equation 4**) in Geoffrion and Graves, i2 formulates the problem using an integer linear program (ILP), with binary variables deciding whether a given railhead serves a particular customer (y_{kl} in Geoffrion and Graves). If fixed costs were considered, and NNA were deciding where to locate a plant or railhead or where to produce a new model, there would also be binary variables deciding whether a facility will open or not. The objective function and all constraints in the model must be linear algebraic functions in order for i2 the ILP to solve. Described below is an illustrative, simplified example of how i2 will construct the ILP objective function for NNA's distribution network.

Figure 9: Illustrative NNA Distribution Network



Suppose that Nissan manufactures products out of two plants. Each plant manufactures a different product. Plant 1 produces Car1 and Plant 2 produces Car2. Each of Nissan's three dealers, Dealers A, B, and C, must obtain its demand for products Car1 and Car2 from each of the plants. Products can travel from the plants to the dealers along a variety of links, as shown in **Figure 9**. For instance, Dealer A can obtain Car1 by sending product from Plant 1 to railhead 3, and then from railhead 3 to Dealer A. Dealer A can also obtain Car1 by sending the product from Plant 1 to railhead 4, and from railhead 4 to Dealer A. i2 will optimize the number of vehicles sent along each link to meet demand. The number of units of a given product sent along each link are the decision variables, represented as $X_{i,j,k}$ [7] in the figure above. In the figure

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[7] The subscripts in the decision variables indicate the flow for each origin (i), destination (j), and product (k) combination.

above, there are twelve decision variables for each of the two products – one for each possible link in the network.

Each link in the network has an associated cost per unit to send a vehicle along that link. This cost per unit includes the contracted rate and the fuel surcharge. The rate can vary depending on the size of the vehicle, so each cost is also associated with a product.

$$Cost\ Per\ Unit\ (C_{i,j,k}) = Transportation\ Rate + Fuel\ Surcharge$$

Equation 8: Cost Per Unit for Transportation Along a Link in the Network

To minimize cost, the ILP will multiply the cost per unit for a given link by the decision variables and decide how many cars will be transported along each link to produce the lowest cost. In the example above, the objective function would be:

$$Min\ (Cost) = C_{1,3,1}X_{1,3,1} + C_{1,4,1}X_{1,4,1} + C_{2,4,2}X_{2,4,2} + C_{2,5,2}X_{2,5,2} + C_{4,6,1}X_{4,6,1} + C_{4,6,2}X_{4,6,2} \dots$$

or, $Min\ (Cost) = \sum_{k=1}^{2}\sum_{j=1}^{9}\sum_{i=1}^{6} C_{i,j,k}X_{i,j,k}$

Equation 9: ILP Objective Function for Illustrative Example

As discussed in 3.1, Geoffrion and Graves, 1974 [9] formulated the same problem in equation 1 in their paper. Their formulation uses a four letter subscript of ijkl, where each link includes the original origin and final destination even if it is an interim path. They discuss the advantages of using this four letter subscript rather than a triple subscript as denoted in Equation 9. They assert that the triple subscript formulation suffers from "a lack of flexibility for some applications because it 'forgets' the origin of a commodity once it arrives at a distribution center [9]." This is particularly a problem when dealing with perishable items where the number of days in transit is important. However, in the case of NNA, it is not necessary, and the triple subscript is simpler, particularly because in NNA, not all paths travel through a railhead (for direct truck), and because there are paths that travel through several railheads such as products traveling north from Mexico. Therefore, it is simpler to keep the decision variables the flow along a particular leg, rather than the total flow through a single railhead.

Of course, like in all ILPs, this ILP minimizes cost subject to some constraints. If there were no constraints in the model, then the ILP would minimize cost by solving that each link should transport zero cars. This would produce a total cost of zero since no vehicles are transported to their destinations. The constraints used by Company A in its model formulation are outlined in the next section.

4.2.3 Model Constraints

All linear optimization problems are bound by constraints. The more constrained the model, the harder it is to solve, and the less optimized the solution. In NNA's distribution model, there are three types of constraints: mathematical constraints in the model itself, constraints due to the processing of data prior to importing that data into the model, and constraints due to the model's structure.

Mathematical Constraints

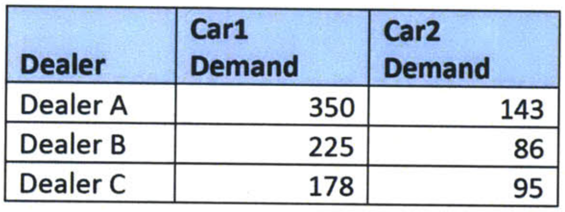
Mathematical constraints limit the solution space by defining a requirement that must be satisfied. Each of these constraints can be turned off and on easily within the model, simply by running the optimization with or without the constraint included.

The first set of constraints is the satisfaction of demand at each dealer. i2 must optimize the flow of vehicles so that the appropriate number of cars reaches each dealer.

NNA forecasts demand at each of the dealers on a monthly basis as part of its sales-marketing efforts. The forecast projects the inventory required to accommodate the retail sales tasks from month to month and is used for production planning at each of the plants. Company A rolls up this monthly forecast as the annual demand requirement in i2.

Illustrative demands at each of the dealers in **Figure 9** are shown in **Figure 10**. Dealer A demands 350 units of Car1 and 143 units of Car2. Dealer B demands 225 units of Car1 and 86 units of Car2. Dealer C demands 178 units of Car1 and 95 units of Car2.

Figure 10: Illustrative Dealer Demands



Dealer	Car1 Demand	Car2 Demand
Dealer A	350	143
Dealer B	225	86
Dealer C	178	95

The total volume coming into each of the dealers for each car, must be greater than or equal to the demand requirement. Therefore, the demand constraint would be written as follows:

Dealer A, Car1: $X_{3,7,1} + X_{4,7,1} \geq 350$

Dealer A, Car2: $X_{4,7,2} \geq 143$

Dealer B, Car1: $X_{4,8,1} + X_{6,8,1} \geq 225$

Dealer B, Car2: $X_{4,8,2} + X_{6,8,2} \geq 86$

Dealer C, Car1: $X_{6.9,1} \geq 178$

Dealer C, Car2: $X_{6,9,2} + X_{5,9,2} \geq 95$

Equation 10: Demand Constraints

In the actual i2 model, these constraints are created for each Nissan and Infiniti dealer and for each Nissan and Infiniti product.

Similar to demand constraints, there are constraints defined for each node indicating that the volume leaving the node cannot exceed the volume flowing into the node. These constraints define the network, and allow the algorithm to understand the feasible paths products could take to fill the demand. An example of this constraint applied to railhead 4, for both Car 1 and Car 2 would be:

Railhead 4, Car1: $X_{1,4,1} \geq X_{4,6,1} + X_{4,7,1} + X_{4,8,1}$

Railhead 4, Car1: $X_{1,4,1} \geq X_{4,6,1} + X_{4,7,1} + X_{4,8,1}$

Equation 11: Network Flow Constraints

Supply chain software will program these network defining constraints on the backend based on the user's input defining the links in the graphical user interface.

The second mathematical constraint is a demand bundle. The demand bundle constrains the solution so that any product from a given manufacturing plant must follow the same path to reach a given dealer. Although A-level and B-level products have different contracted rates for different paths, i2 will ensure that all A-level and B-level products from the same plant will follow the same path to a particular dealer. Often B-level products are routed on a less preferable path because it is cheaper for A-level products to follow that path. Suppose, for instance, that plant 1 in **Figure 9** manufactures Truck3 in addition to Car1. It may be cheaper for Truck3 to travel to Dealer A via railhead 4, while it is cheaper for Car1 to travel to Dealer A via railhead 3. Because there is a higher volume of Car1 than there is Truck3, NNA must send all products from Plant1 to Dealer A through railhead 3. NNA is constrained to create only one possible path for a given origin-destination because of limitations in its information technology. This constraint is similar to the single distribution center per demand region constraint, **Equation 4** in Geoffrion and Graves, 1974 [9], discussed in section 3.1.

The next set of constraints deal with minimum and maximum volumes for each of the flows. Volume and capacity constraints link the dealers together and create the need of solving a global optimization. Without volume or capacity constraints, each dealer's route could be solved independently of the others to minimize total cost. Volume and capacity constraints create limitations that can cause the model to compromise cost for one dealer in favor of a lower network cost. Volume and capacity constraints are contained within **Equation 5** in Geoffrion and Graves, 1974 [9].

Company A constrains the volume out of the port of Veracruz for Mexican products to its current volume. This is due to a railcar limitation for the link between the plant in Aguascalientes and the port. Suppose that the capacity is constrained to 50,000 vehicles annually. Because only two vehicles are produced in Mexico, the constraint would be written as the sum of the flow of the two products from Aguascalientes to Veracruz.

$$X_{A,V,S} + X_{A,V,V} \leq 50{,}000.$$

Equation 12: Capacity Constraints

Section 5.1 of this paper discusses the savings opportunities arising from creative solutions to expanding capacity out of Veracruz.

In addition to the Veracruz capacity constraint, which places a limit on the flow volume, there are also minimum volume requirements that each rail-leg and railhead must meet. These are due to contractual obligations to the rail carriers. Each railhead that NNA uses for routing must process at least 3000 units per year, and each rail-leg must transport a minimum of 500 units per year. Continuing with the example from **Figure 9**, and focusing on railhead 4, the mathematical constraints are as follows:

Railhead 4 must process at least 3,000 units per year. Suppose that Plant1 produces both Car1 and Truck3 and that Plant2 produced just Car2. The sum of the flows of each of these products into railhead 4 must be greater than or equal to 3,000. If the solver finds that it is impossible to send 3,000 units to railhead 4, that railhead will not be used, and i2 will find an alternate path to reach the dealers, so long as the constraints are met. If the solver is unable to find a suitable path that meets this requirement, it will throw an error, and the constraint will need to be relaxed.

$$X_{1,4,1} + X_{1,4,3} + X_{2,4,2} \geq 3{,}000$$

Equation 13: Railhead Minimum Volume Constraint

In addition to the minimum flow at the railhead, each rail leg flow must be at least 500 units per year. Product Car1 and Truck3 both follow the path (1,4), while Car2 follows the path (2,4). The volume on both (1,4) and (2,4) must be at least 500 units to use that path.

$$X_{1,4,1} + X_{1,4,3} \geq 500$$

$$X_{2,4,2} \geq 500$$

Equation 14: Rail Leg Minimum Volume Constraint

Other constraints, unique to NNA's carrier agreements, are also included in the model. However, this paper will not dive into the mathematical formulations. i2 is fully capable of including any additional restrictions in the model that further constrain the solution. These are represented by **Equation 6** in section 3.1, which include all miscellaneous constraints beyond those discussed above.

Constraints Due to the Pre-processing of Data

The i2 model will only be as robust as the data that is fed into it. By including more data, the model will have greater flexibility and more choices on which to optimize. Currently, Company A pre-filters the data before it is loaded into i2. While this can speed up the solving time, it also limits the solution set. Company A will take out any railhead that is not currently open for use by NNA and any Company A vehicle processing center that is not currently active. For short term routing changes, this can make sense, since it takes time to open a new railhead or to activate a processing center. However, for long-term strategic planning, it would be good to know what the routing would look like unconstrained if vehicles could route to alternative locations. Company A also filters out any alternate trucking route greater than 500 miles. This based on typical travel distances within the Department of Transportation Hours of Service regulations. While typical driving daily distances should be a factor, it is possible that a long haul trucking lane can still be cheaper than a rail leg, even with an overnight stay. NNA would need to include these trucking routes in the model to fully understand their impact.

Structural Constraints

While i2 has a very simple and easy to use graphical user interface, basic knowledge of optimization is required to understand how to structure the model. Structural constraints are those constraints that are unintentional. They are caused by the way the model was designed, rather than by manual input. There are several structural constraints in the model, each of which keep the optimization from being as flexible as it should be to obtain the most cost effective solution.

Company A will only optimize NNA's network based on current contracts. Therefore, even if a particular railhead or vehicle processing center is currently in use for products from one location, that railhead may not be used for products from another. In the example above (**Figure 9**), products from both Plants 1 and 2 are able to use railhead 4. However, only products from Plant 1 can use railhead 3. Suppose there is, in fact, a rail lane from Plant 2 to railhead 3. i2 will not have the option of sending products from Plant 2 to railhead 3 even if the rate for this rail leg is cheaper because the leg has not been defined in the model. Additionally, even rail legs that have been defined may not be able to carry every product. In i2, interfacility links are created on an origin, destination, product basis so that the program can determine the number of units of each product on a given origin destination link. As described above, decision variables are based on an origin, destination, and product combination. If a given origin-destination link is not defined for a particular product, the program cannot send that product on that link. For instance, for Nissan, products from Smyrna travel through Buffalo to get to Halifax along a Buffalo-Halifax link. However, this Buffalo-Halifax link is not defined for Mexican product. Therefore, Mexican product is routed to Halifax through Chicago, rather than Buffalo. i2 does not have the flexibility to choose between Chicago and Buffalo for Mexican product, even though Company A holds contracts for both the Buffalo-Halifax and Chicago-Halifax lanes.

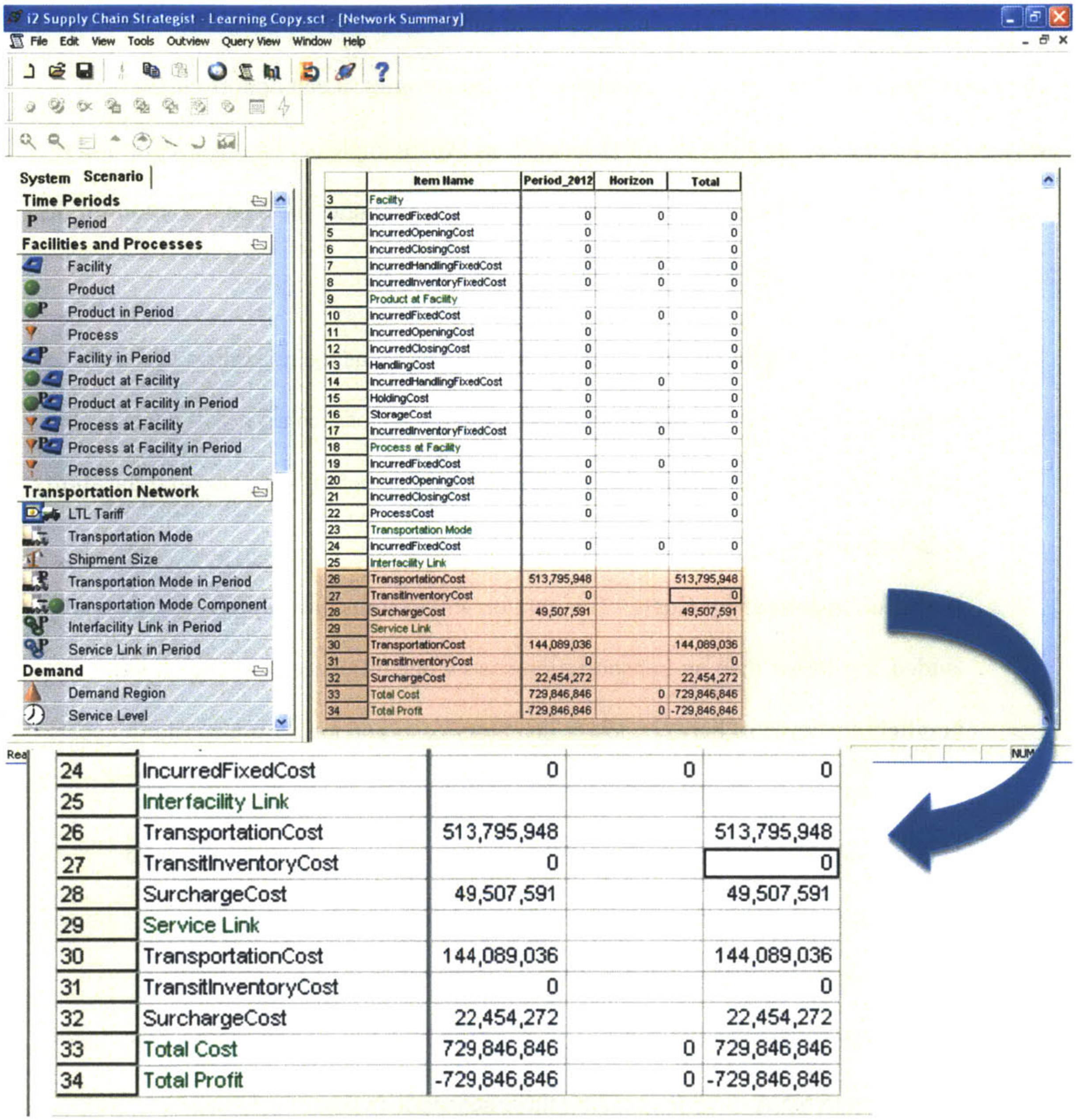
4.3 Current Model Output

i2 will solve for each flow along each link for each product such that demand is met at each dealer. It will solve for each $X_{i,j,k}$ represented in **Figure 9**. i2 also allows the user to view network summaries of total costs to compare to another scenario. A screenshot of a network summary is shown in **Figure 11**. In the network scenario displayed in **Figure 11**, the total transportation cost is about $730 million. Only costs for the transportation links are included, not those for transit inventory.

In addition to the network summary, i2 allows the user to view combinations of flows on a map, showing the optimized links. It also has the capability to color code the links by flow volume. This capability is useful to visualize how the routes change from one scenario to another.

Unlike spreadsheet optimizers, i2 lacks the ability to conduct sensitivity analysis on a constraint. The only way to perform a sensitivity analysis on a constraint using i2 is by manually adjusting parameters and running a new scenario and seeing how the solution changes.

Figure 11: Current Network Summary



	Item Name	Period_2012	Horizon	Total
3	Facility			
4	IncurredFixedCost	0	0	0
5	IncurredOpeningCost	0		0
6	IncurredClosingCost	0		0
7	IncurredHandlingFixedCost	0	0	0
8	IncurredInventoryFixedCost	0	0	0
9	Product at Facility			
10	IncurredFixedCost	0	0	0
11	IncurredOpeningCost	0		0
12	IncurredClosingCost	0		0
13	HandlingCost	0		0
14	IncurredHandlingFixedCost	0	0	0
15	HoldingCost	0		0
16	StorageCost	0		0
17	IncurredInventoryFixedCost	0	0	0
18	Process at Facility			
19	IncurredFixedCost	0	0	0
20	IncurredOpeningCost	0		0
21	IncurredClosingCost	0		0
22	ProcessCost	0		0
23	Transportation Mode			
24	IncurredFixedCost	0	0	0
25	Interfacility Link			
26	TransportationCost	513,795,948		513,795,948
27	TransitInventoryCost	0		0
28	SurchargeCost	49,507,591		49,507,591
29	Service Link			
30	TransportationCost	144,089,036		144,089,036
31	TransitInventoryCost	0		0
32	SurchargeCost	22,454,272		22,454,272
33	Total Cost	729,846,846	0	729,846,846
34	Total Profit	-729,846,846	0	-729,846,846

24	IncurredFixedCost	0	0	0
25	Interfacility Link			
26	TransportationCost	513,795,948		513,795,948
27	TransitInventoryCost	0		0
28	SurchargeCost	49,507,591		49,507,591
29	Service Link			
30	TransportationCost	144,089,036		144,089,036
31	TransitInventoryCost	0		0
32	SurchargeCost	22,454,272		22,454,272
33	Total Cost	729,846,846	0	729,846,846
34	Total Profit	-729,846,846	0	-729,846,846

PART 5: Opportunities for Improvement

This project identifies several opportunities for improvement in NNA's current optimization model. This thesis will focus on three key high-level opportunities. Each opportunity will feature case studies within the NNA distribution network where implementing the opportunity will yield cost savings. To protect NNA's proprietary data, actual rates have been altered for the purposes of this paper. The three key cost-saving opportunities are:

1. **Increased Model Flexibility.** This section will examine the relaxation of the network's mathematical and structural constraints. In particular, it will consider the addition of more alternative routes, increased volume out of Veracruz, and the ability to have multiple routes per origin-destination pair.
2. **Inclusion of Inventory Costs.** This section will examine how optimizing on total landed cost rather than on transportation costs alone influences routing. It will highlight the tradeoff between lower inventory costs and higher transportation costs using a case study of particular routes from Wilmington, CA.
3. **Understand Model Sensitivities.** While i2 does not have the capability of a sensitivity output, it is important to understand the input sensitivities before contract negotiations and in advance of environmental or other emergencies. This section will provide guidance regarding how a sensitivity analysis should be done in i2 and the benefit to NNA of understanding these sensitivities proactively to create a more responsive supply chain.

5.1 Increased Model Flexibility

By increasing the flexibility on the model, the optimizer can choose between increased alternatives. With more alternatives, it is often the case that a better solution can be found.

Increased flexibility is achieved by relaxing model constraints. There are two types of model constraints: those that truly constrain the solution and those that do not. It is possible that a constraint does not truly constrain the model if there exists another constraint that constrains it more. For instance, suppose the maximum capacity of a railhead is two million units per year. However, total demand that must be satisfied is only 1.5 million units per year. The capacity constraint would not affect the solution because even if all 1.5 million units were routed through that railhead, the two million limit would not be constraining. Increasing flexibility in the model will only yield a better solution by relaxing constraints that truly constrain the model and increasing the "feasible region" of the solution space.

This section will explore the relaxation of three constraints through case examples within the NNA network. First, it will study the relaxation of capacity constraints through a study of increasing volume out of Veracruz. Next, it will look at the relaxation of structural constraints through the addition of more alternative routes – Veracruz to Port Elizabeth for NMEX products, and Chicago to Halifax for Smyrna products. Finally, the section will examine the possibility of routing A level and B level products separately, again through the case of Smyrna products headed to Halifax.

Increased Capacity

Capacity constraints limit the flow of products through a particular facility. The capacity constraint is represented by the right half of **Equation 5** in Geoffrion and Graves, and Equation 12 in the NNA network. Capacity could be constrained for a number of reasons, including the size of the facility, the workforce available at the facility, the equipment available at the facility, or the transportation capacity into or out of the facility. There are several ways to relax capacity constraints including increasing the size of the facility, hiring additional labor, or purchasing more equipment. Capacity can also be increased by operational improvements that generate greater efficiency in the space, labor, and equipment available. The decision to increase capacity must be evaluated by weighing the cost of increasing capacity versus the net present value of the savings by doing so.

In the case of NNA, there is a limit on the flow of vehicles through the Port of Veracruz. This constraint is due to a railcar shipping limitation for the rail leg from the production plant in Aguascalientes to the port. By removing this mathematical constraint in the model, NNA would save about one million dollars a year with its current network. NNA would be able to achieve this increased capacity by either working with the railroads to gain access to more railcars or by trucking volume to the port instead of sending it by rail. While both of these solutions may not be worth the savings under the current network, they are certainly worth exploring when evaluating alternative routes out of Veracruz, explained below.

More Alternative Routes

In addition to relaxing mathematical constraints in the model, NNA can relax structural ones by including more alternative routes in the model. Increasing the number of alternatives allows the optimizer to have more options to choose from.

Case Study: Veracruz to Elizabeth for NMEX Products

Under the current network, NNA sends products produced in Mexico (NMEX product) by ocean from Veracruz to Jacksonville and Baltimore for distribution to the East coast[8] of the United States. NNA's ocean carrier makes one stop at Jacksonville and one stop in Baltimore

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[8] Currently, the northeast coast is excluded from this ocean routing.

using the same vessel. As shown in Appendix 6, products bound for the northeast travel via rail from the plant to the U.S. border, the border to East St. Louis, and from East St. Louis to railheads in the northeast. Using the i2 software, NNA could evaluate the alternative of sending products bound for the northeast via ocean by having the ocean carrier make an additional stop at Port Elizabeth. Port Elizabeth is a logical choice for a port in the northeast since it is already used by NNA to process vehicles from Japan bound for the northeast. NNA could therefore use the same truck carriers it uses for Japan sourced products to distribute its NMEX products in the northeast.

i2 has the capability of evaluating several scenarios. When adding an additional route, the carrier's rate is usually unknown, since the route has yet to be negotiated. Therefore, when evaluating a potential new route, a Company should conduct a scenario analysis by evaluating the profitability of the additional route at a variety of rates. Because the rate that the ocean carrier would charge from Veracruz to Elizabeth is unknown, the Company must use the rate from Veracruz to Baltimore as a base rate and then evaluate the proposed new route under various alternative rate conditions. Suppose the rate from Veracruz to Baltimore were $200 per unit. The route to Elizabeth is evaluated at this base level of $200, as well as at base +10%, base +20%, base +30%, etc. The total cost for each of these scenarios would then be compared to the current total cost to understand the cost savings. **Figure 12** shows projected cost savings for each of these scenarios. Even at $300, which is the base level + 50%, NNA would save $5 million by opening the Veracruz – Elizabeth ocean lane.

Figure 12: Projected Cost Savings for Rate Scenarios from Veracruz to Elizabeth

Varacruz - Elizabeth Ocean Rate	Cost Savings
$200	$10 M
$220	$9 M
$240	$8 M
$260	$7 M
$280	$6 M
$300	$5 M

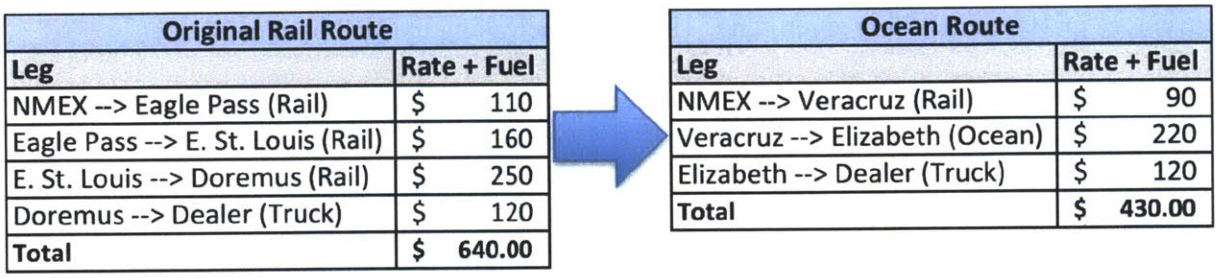
The cost savings above assume unrestricted capacity out of Veracruz. As discussed, Veracruz's capacity is constrained due to a railcar shortage. With higher cost savings due to the opening of the Veracruz – Elizabeth lane, it is worth considering ways to increase the capacity out of Veracruz.

The constrained capacity out of Veracruz limits the savings from opening this alternative route, but there remains an annual cost savings of about $1 million. When opening this alternative lane subject to constrained capacity, i2 will optimize based on which dealers yield the largest savings through ocean service over rail service. Therefore, by opening this lane, several northeast dealers previously serviced via rail, will now be serviced via ocean by taking ocean volume previously routed to Jacksonville or Baltimore. Suppose the capacity constraint at Veracruz is 50,000 units as shown in Equation 12, and suppose that 15,000 of these units are currently routed to Jacksonville, and that 35,000 of these units are currently routed to Baltimore. By opening the Veracruz – Elizabeth lane, the total volume out of Veracruz would remain at 50,000, but would be broken up by sending 15,000 units to Elizabeth, 5,000 units to Jacksonville, and 30,000 units to Baltimore.

The savings by routing the vehicles via ocean to Elizabeth rather than routing them via rail vary at a dealer level. As shown in **Figure 13**, the cost savings at one dealer could be $210 per unit, while $65 at another.

Figure 13: Projected Cost Savings at Two Dealers

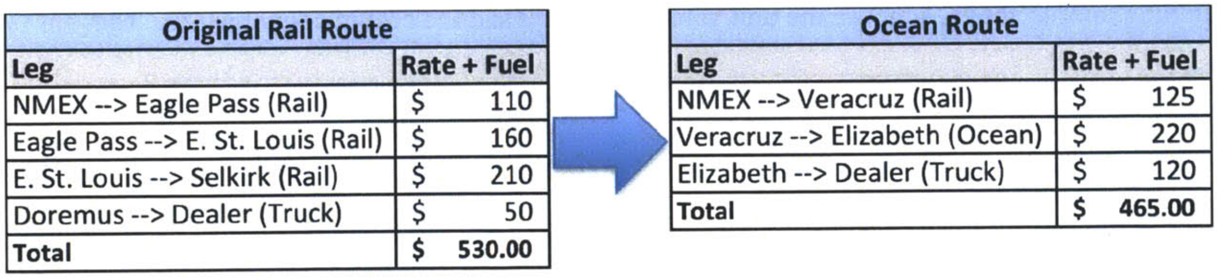
Dealer: Garden City, New York Cost Savings: $210



Original Rail Route	
Leg	**Rate + Fuel**
NMEX --> Eagle Pass (Rail)	$ 110
Eagle Pass --> E. St. Louis (Rail)	$ 160
E. St. Louis --> Doremus (Rail)	$ 250
Doremus --> Dealer (Truck)	$ 120
Total	**$ 640.00**

Ocean Route	
Leg	**Rate + Fuel**
NMEX --> Veracruz (Rail)	$ 90
Veracruz --> Elizabeth (Ocean)	$ 220
Elizabeth --> Dealer (Truck)	$ 120
Total	**$ 430.00**

Dealer: Schenectady, New York Cost Savings: $65



Original Rail Route	
Leg	**Rate + Fuel**
NMEX --> Eagle Pass (Rail)	$ 110
Eagle Pass --> E. St. Louis (Rail)	$ 160
E. St. Louis --> Selkirk (Rail)	$ 210
Doremus --> Dealer (Truck)	$ 50
Total	**$ 530.00**

Ocean Route	
Leg	**Rate + Fuel**
NMEX --> Veracruz (Rail)	$ 125
Veracruz --> Elizabeth (Ocean)	$ 220
Elizabeth --> Dealer (Truck)	$ 120
Total	**$ 465.00**

One consequence of routing vehicles via ocean instead of routing them via rail is the increased lead time. Ocean freight from Veracruz to the northeast dealers takes about 30 days[9], while rail freight from Veracruz to the northeast dealers takes about 20 days. This increased lead time will both decrease customer service by increasing time from order to delivery and will increase inventory costs. The inclusion of inventory costs in the model will be explored in

---

[9] Lead times include both transit times and dwell times at ports and railheads. They assume current dwell times based on the current frequency of vessels to the Northeast.

section 5.2. However, because inventory costs are not currently included in the model costs, the potential inventory implications must be calculated to determine the true effect of opening the Veracruz-Elizabeth lane.

Increases in inventory costs are calculated by looking at the increased number of units in the pipeline necessary because of the increased lead time. For instance, suppose the sales volume at a dealer is 5 units per day. With a lead time of 20 days, that dealer needs pipeline inventory of 100 units at any given time. However, increasing the lead time to 30 days, would mean that the dealer needs 150 units in pipeline inventory at any given time. The difference in inventory cost is calculated as follows:

$$\Delta Inventory\ Costs = \Delta Inventory\ Units * Unit\ Value * Cost\ of\ Capital$$

Equation 15: Increase in Inventory Costs

In the example above, suppose the unit value is $20,000 and the cost of capital is 8%. The additional cost of holding 50 extra units of inventory would be $80,000 per year. With all of the dealers in the NNA network, the increased inventory cost of opening up the Veracruz-Elizabeth lane with unconstrained capacity is about $1.5 million. Therefore, the true savings from opening this lane is the savings after the inventory cost increase is subtracted, as shown in **Figure 14**.

Figure 14: Projected Cost Savings for Rate Scenarios After Inventory Costs are Subtracted

Veracruz - Elizabeth Ocean Rate	Cost Savings	True Saving after Inventory Cost Increase
$200	$10 M	$8.5 M
$220	$9 M	$7.5 M
$240	$8 M	$6.5 M
$260	$7 M	$5.5 M
$280	$6 M	$4.5 M
$300	$5 M	$3.5 M

Case Study: Chicago to Halifax for Smyrna Products

As mentioned in the discussion of NNA's structural constraints in section 4.2.3, i2 defines links between facilities on an origin, destination, product basis. If a given origin-destination link is not defined for a particular product, the program cannot send that product along that link. For instance, products from Smyrna travel through Buffalo to get to Halifax along a Buffalo-Halifax link, while products from Mexico travel through Chicago to get to Halifax along a Chicago-Halifax link. The Buffalo-Halifax link has not been defined in the model for Mexican sourced products, and the Chicago-Halifax link has not been defined for Smyrna sourced products. i2 does not have the flexibility to choose between Chicago and Buffalo for Mexican or Smyrna products and must send those products along the links defined, even though Company A holds contracts for both the Buffalo-Halifax and Chicago-Halifax lanes.

Another way to relax structural constraints is to ensure that every contracted lane is defined for every product. As an example, we will look at the costs of routing the Frontier, a small truck produced in Smyrna, through Chicago, rather than through Buffalo to get to Halifax.

Figure 15: Projected Cost Savings in Transporting Frontiers to Halifax Through Chicago

Through Buffalo

Leg	Cost
Smyrna → Buffalo (Rail)	$220
Buffalo → Halifax (Rail)	$650
Total	**$870**

Through Chicago

Leg	Cost
Smyrna → Chicago (Rail)	$250
Chicago → Halifax (Rail)	$560
Total	**$810**

As **Figure 15** shows, it is $60 per unit cheaper to send Halifax-bound Frontiers through Chicago over Buffalo. If NNA were to relax similar constraints throughout its network by associating each product with each possible link in the model, savings could be substantial.

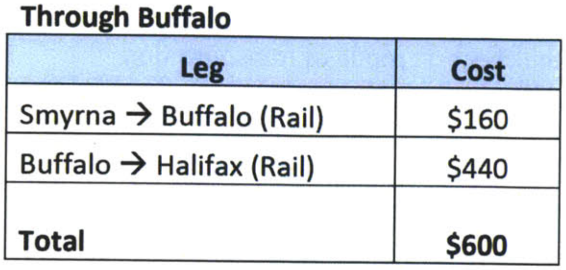
Multiple Routes per Dealer

A constraint in NNA's IT systems permits only one possible routing solution for each origin-destination pair. However, product from an origin can have different rates depending on its size. Smaller vehicles such as sedans and sports cars have lower transportation rates, and are considered A-level products. Small trucks and SUVs have higher transportation rates and are considered B-level products. Larger trucks have even higher rates and are considered C-level products. A-level and B-level products are not able to travel different paths to the dealers even though they have different contracted rates. i2 will solve by selecting the route for the O-D pair with the lowest weighted average cost among all products.

Case Study: Chicago to Halifax for Smyrna Products

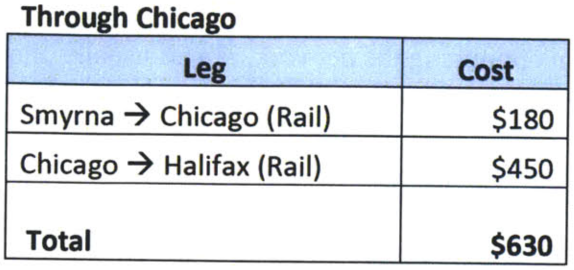
The case above shows the costs for routing Frontiers, a B-level Smyrna product through Chicago versus through Buffalo in order to get to Halifax. As shown, it is $60 cheaper to send B-level products from Smyrna to Halifax through Chicago. However, the opposite is the case for A-level products.

Figure 16: Projected Cost Savings to Transport A-level Products to Halifax Through Chicago



Through Buffalo

Leg	Cost
Smyrna → Buffalo (Rail)	$160
Buffalo → Halifax (Rail)	$440
Total	**$600**



Through Chicago

Leg	Cost
Smyrna → Chicago (Rail)	$180
Chicago → Halifax (Rail)	$450
Total	**$630**

As shown in **Figure 16**, it is $30 cheaper to route A-level product through Buffalo. Currently, NNA is not able to have multiple routes per O-D pair. However, if it were able to, it could send A-level products through Buffalo and B-level products through Chicago. With the constraint in place, i2 will optimize and choose the route for all products with the lowest weighted average cost. Therefore, if the ratio of A-level to B-level products going to Halifax is greater than 2:1, i2 will choose the route through Buffalo. However, if the ratio of A-level to B-level products going to Halifax is less than 2:1, i2 will chose the route through Chicago.

The total cost savings by eliminating the single route per dealer constraint is over $250,000 per year. NNA needs to evaluate the cost of upgrading its database to allow for multiple routes per dealer to determine the true net present value of eliminating that constraint.

5.2 Inclusion of Inventory Costs

When optimizing routing, NNA only includes its spend to the carriers in rates and fuel as components of the transportation cost. As discussed in the literature review in section 3.2, NNA should optimize based on its "total landed cost" of transportation. There are several components to total landed cost besides transportation spend, including storage costs, inventory costs, probability of damage, packaging, and customs and duties. This section will focus on cost savings due to the inclusion of inventory costs.

NNA does not currently consider inventory costs when optimizing its routing. Therefore, when optimizing the network, i2 will usually choose the cheapest mode of transportation regardless of its speed of delivery[10]. Usually, the slower modes of transportation, such as ocean, are cheaper than faster ones, such as trucks. By reducing transportation costs, NNA is creating longer lead times. The effect of longer lead times on inventory is two-fold:

1) Longer lead times lead to additional inventory in the pipeline.
2) Longer lead times require an increase in safety stock at the dealers.

Effect of Lead Time on Pipeline Inventory

Pipeline inventory is referred to as inventory in transit. This concept was illustrated in section 5.1, in the Veracruz example. In the above example, the difference in pipeline inventory costs is calculated using Equation 15. i2 calculates the inventory cost per unit to travel a particular path and adds this amount to the transportation unit cost to determine the total landed cost per unit. Transit inventory costs in i2 are calculated using Equation 16. The longer the lead time, the longer the inventory unit cost.

$$Inventory\ Unit\ Cost = Unit\ Value * Cost\ of\ Capital * \frac{Leadtime}{365}$$

Equation 16: Calculation of Transit Inventory Cost per Unit in i2

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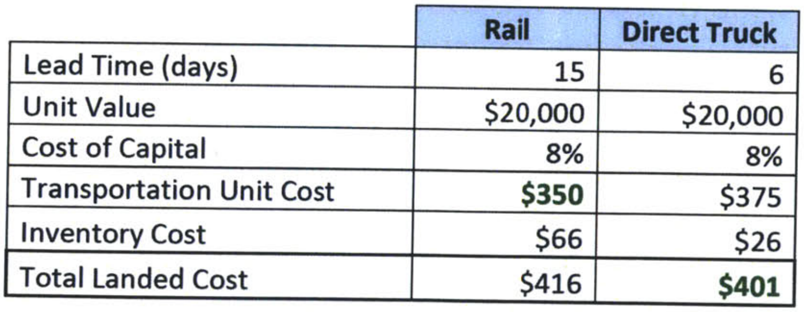
[10] NNA's sales and marketing group considers the impact of lead time on a customer and provides input on acceptable lead times outside of the model.

i2 will calculate the total landed cost as the sum of the inventory cost and the transportation cost. By including inventory costs in the model, there can be cases where i2 will choose a more expensive path due to its shorter lead time, as shown in the following example.

Suppose there are two possible paths for a vehicle. One path ships cars by rail to a railhead and the cars are then trucked to the dealer from the railhead. Another path ships vehicles by trucks directly to the dealer from the plant. The first path has a lead time of 15 days, while the second has a lead time of 6 days. The unit value of the product is 20,000, and the cost of capital of 8%. Without including inventory costs, it is $25 cheaper to send the product by rail than by direct truck. However, when calculating the inventory costs, it becomes cheaper to send the product by direct truck because of the significant inventory savings (see **Figure 17**). With each vehicle of this model shipped to this dealer, NNA would save $15. Across the entire network of 1.2 million vehicles shipped annually, NNA could generate significant savings through the inclusion of inventory costs.

Figure 17: Illustrative Rerouting Due to Inclusion of Inventory Costs



	Rail	Direct Truck
Lead Time (days)	15	6
Unit Value	$20,000	$20,000
Cost of Capital	8%	8%
Transportation Unit Cost	**$350**	$375
Inventory Cost	$66	$26
Total Landed Cost	$416	**$401**

Effect of Lead Time on Safety Stock

Larger lead times also lead to the need for larger safety stock at the dealers. This should also be included in the total landed cost. The formula for safety stock is shown in **Equation 17**. Lead time in the equation is represented as a fraction of the year. For instance, if the lead time is 15 days, then the lead time in the equation would be 15/365.

$SS = z * \sqrt{Leadtime * \sigma_D^2 + Demand^2 * \sigma_L^2}$, where σ_D is the standard deviation of demand, and σ_L is the standard deviation of lead time [18].

Equation 17: Formula for Safety Stock

The equation for safety stock is non-linear. Because the network model is an ILP, it cannot be included in the cost function. To deal with this, the cost of safety stock for route alternatives is calculated outside the model and is added to the resulting total cost of the optimization for each scenario.

Suppose a dealer desires a service level of 95%. Under a normal distribution, this corresponds to a Z value of 1.65[11]. Demand for the product at the dealer is 1800 units per year, with a standard deviation of 500 units. Using the same two possible paths described above, rail with a lead time of 15 days and direct truck with a lead time of 6 days, the difference in safety stock needed at the dealer for the two possible routes can be calculated. Suppose, for simplicity, that there is no variation in lead time. In this case, safety stock is 61 units higher by shipping via rail than by direct truck. This results in about $100,000 more in annual holding costs at the dealer.

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[11] In a normal distribution (mean=0, standard deviation = 1), 95% of the distribution will fall below the Z value of 1.65.

Figure 18: Difference in Cost of Safety Stock at Dealers in Routing Alternatives

	Rail	Direct Truck
Lead Time (days)	15	6
Unit Value	$20,000	$20,000
Cost of Capitol	8%	8%
z-score	1.65	1.65
Annual Demand	1,800	1,800
Standard Deviation of Demand	500	500
Safety Stock	**167**	**106**
Holding Cost of Safety Stock	**$267,592**	**$169,240**

Nissan's North American dealers are independently owned. Therefore, NNA recommends inventory and builds production plans based on targeted dealer inventory. It is highly critical to ensure that dealers do not stock out or miss retail sales, however, financially NNA does not account for the costs of holding inventory in its own financial analysis.

Case Study: NML Products through Wilmington

This study will examine particular Nissan products sourced from Japan (NML) that travel through the port of Wilmington, outside of Los Angeles, for distribution. Currently, products travelling to California, Nevada, Utah, and Arizona are trucked directly from the port, while products traveling to other portions of the country and distributed via rail, and then trucked to the dealers from the railheads (See Appendix 3).

Because of dwell times[12] at the plant and the railheads for rail transit, the lead times for finished vehicles shipped by rail are significantly longer than for those sent by direct truck to the

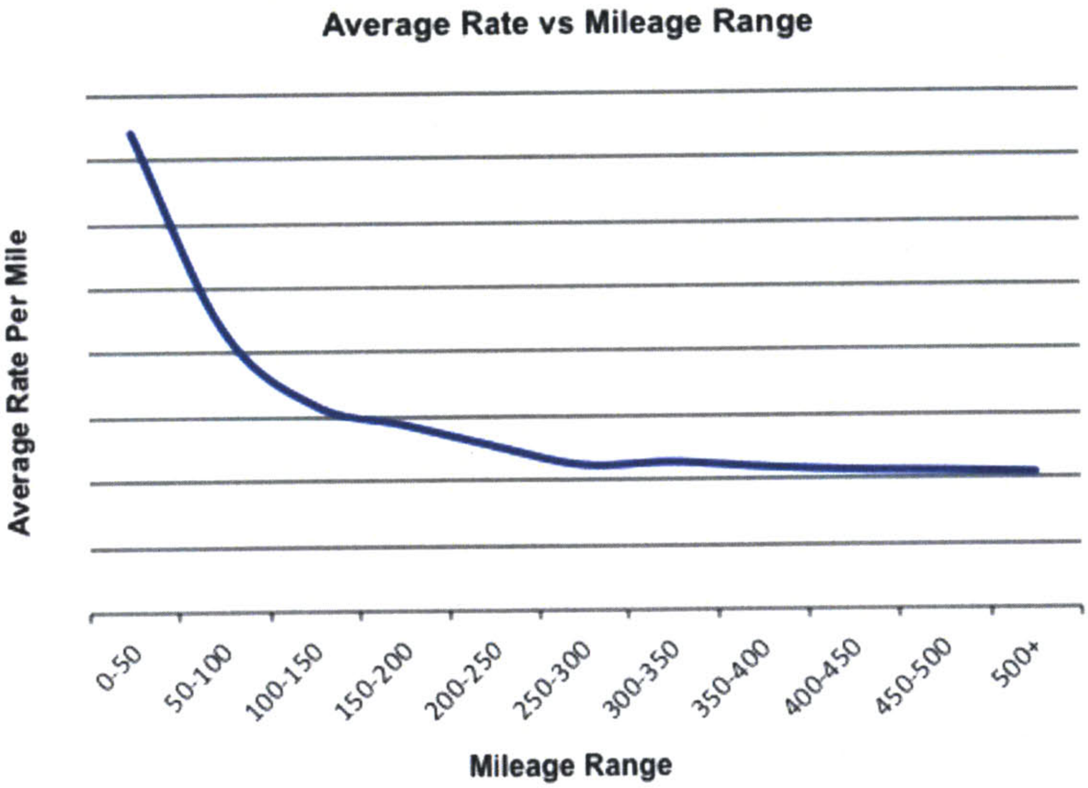
---

[12] Dwell times are typical before transport. They exist due to inventory buffers and wait times for enough finished products to create a full load for a railcar destined for a particular railhead.

same dealer. By including the inventory costs in the model, the boundary to where NNA sends its products by direct truck is extended.

In addition to the lower inventory costs, including longer haul truck routes also takes advantage of economies of scale unique trucking. Truck contracts are constructed with a fixed cost for the route plus a cost per mile. Therefore, longer haul routes will have a lower cost per mile than shorter haul routes, as shown in **Figure 19.**

Figure 19: Truck Rates Per Mile Decrease With Longer Haul Routes



Consider the Rogue, a B-level product, out of the port of Wilmington. The Rogue comes from Japan and is distributed through Wilmington to the western portion of the United States.

Currently, the product is distributed by direct truck to dealers in California, Nevada, Utah, and Arizona. Dealers in other states are supplied by rail and then by truck from the railheads. However, including inventory costs in the model, there are dealers in New Mexico and Oregon that are better serviced by direct truck, similar to the illustrative example in **Figure 17**. By including inventory costs in the routing of Rogues out of Wilmington, NNA will increase its cash flow by over $150,000 annually. Expanding this concept to other products and other origins will further increase this savings.

5.3 Understand Model Sensitivities

Distribution network models are too complex to solve if incorporating uncertainty. The models assume that all costs are known and that uncertainty does not affect the solutions and insights [1]. However, uncertainty and risk do have a significant impact on a Company's supply chain choices. Therefore, it is critical that NNA understands the sensitivity of the output to fluctuations and uses the knowledge as an aid during carrier contract negotiations. Using the model as a proactive tool by running "what-if" scenarios would help NNA understand the impact of changes in rates and fuel prices to the optimum design of its network.

Understanding the model sensitivities also will allow NNA to have a more responsive supply chain due to environmental and other externalities. Environmental externalities disrupt the current supply chain. By understanding the costs of alternatives in advance of such occurrences, NNA would be able to respond immediately. An example of such an externality is the tsunami in Japan in 2011. During this time, there were part shortages, and Nissan was able to respond quickly and effectively to the disaster. However, if it had understood the alternatives before the event, its reaction may have been even quicker. In its 2012 Supply Chain Management Buyer's Guide, Technology Evaluation Center, a software consulting firm, provided some examples of externalities that supply chain software could study preemptively [19]:

- What if a truck driver shortage impedes transportation capacity?
- What happens to the supply chain after a merger or acquisition?
- What if a natural disaster disables a key supplier?
- What if a Company has to locate and reroute a critical shipment in-transit?
- How does a Company trace the source of product contamination?

Toyota created a model that allowed it to understand the alternatives for distribution of its spare parts [16]. Toyota created a tool to optimize the distribution. Unlike the i2 software, the Toyota tool generates a set of high-quality but structurally different solutions, rather than a single one. "This increases Toyota's negotiating power, increases its ability to analyze its current transport network against possible alternatives, and allows it to quickly switch between different transport networks if unexpected events occur. [16]." NNA could similarly benefit by analyzing multiple solutions.

In i2, the only way to understand sensitivities and alternatives in the model is through scenario analysis. Scenario analysis is critical to flexibility should conditions change and is important for understanding rate sensitivities prior to contract negotiations. This section will examine routing changes due to changes in fuel prices.

Kim and Nsiah-Gyimah (2009) examined the impact of fuel price volatility on transportation mode choice [7]. In particular, they created a mathematical equation to determine the fuel price at which it made sense for a Company to switch between direct truck and rail combined with truck [7]. As part of the predetermined contract agreements, fuel surcharge rates do not increase equally with an increase in the price of crude oil. Additionally, fuel is a smaller portion of the total rate for rail than it is for trucks. Therefore, a change in crude oil affects the cost of truck transport more than it does rail transport. Kim and Nsiah-Gyimah assume that for every $0.06 increase or decrease in crude oil, truck rates increase or decrease by $0.01 per mile and rail rates increase or decrease by $0.0075 per mile [7].

The rates in carrier contracts reflect several components:

- A fixed transportation rate for any route by the carrier (B_f).
- A variable per mile transportation rate (B_v).
- A fixed fuel charge negotiated into the contract, typically 10% of the total transportation rate, but lower for rail. This charge is based on a negotiated base price for crude oil (C_n).
- A fuel surcharge that either charges or refunds for differences between the actual price of crude oil (C_a) and the negotiated base price.

Suppose that for rail, the base fuel cost is 8% of the total rate, while for truck it is 12% of the rate. The equations for each mode of transportations are as follows:

$$Rail\ Cost = [B_f + B_v * miles] + 0.08 * [B_f + B_v * miles] + \frac{C_a - C_n}{0.06} * 0.0075 * miles$$

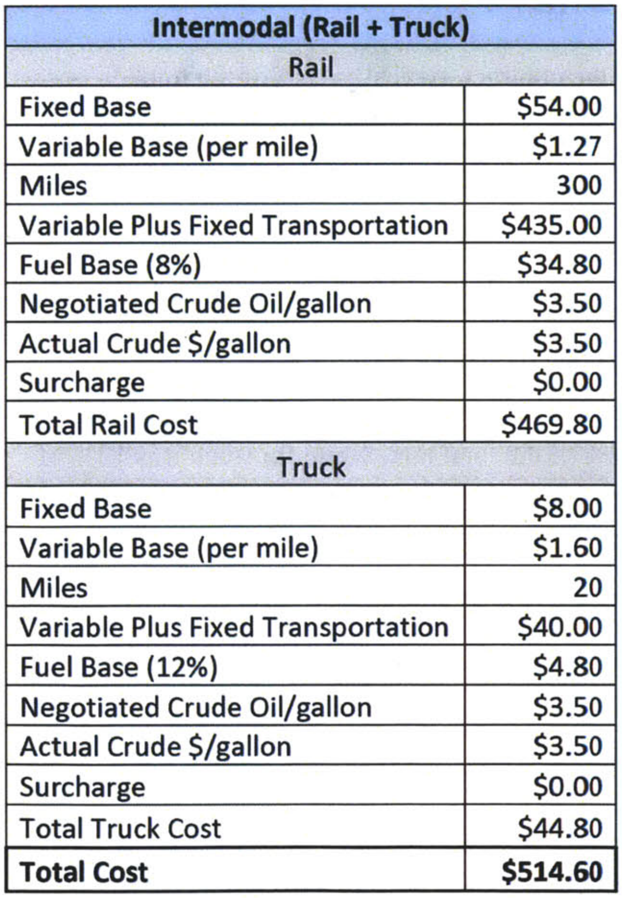
$$Truck\ Cost = [B_f + B_v * miles] + 0.12 * [B_f + B_v * miles] + \frac{C_a - C_n}{0.06} * 0.01 * miles$$

Equation 18: Transportation Rate Equations Including Fuel for Rail and Trucks

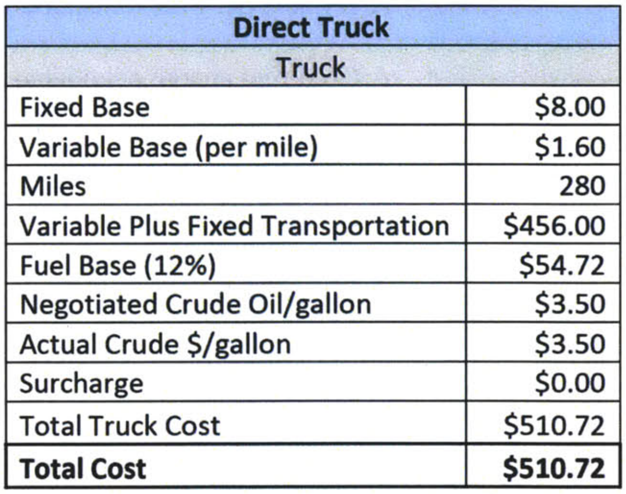
Suppose the following route, where there is a choice between intermodal transportation and direct truck. The fixed rate of rail is $54 per unit, while the base rate of truck is $8 per unit.

The variable price for rail is $1.27 per mile per unit, while the variable price for truck is $1.60 per mile per unit. The intermodal choice requires 300 rail miles and 20 truck miles from the railhead to the dealer. The direct truck option is 280 truck miles. The negotiated price of crude is $3.50 per gallon. If the actual price of crude is $3.50, then there is no surcharge, and it is $4 cheaper per vehicle to route vehicles via direct truck, as shown in **Figure 20**. When the price of crude, rises by a dollar, to $4.50, it is $2 cheaper per vehicle to route by rail, as shown in **Figure 21**.

Figure 20: Intermodal vs Direct Truck with the Price of Crude Oil at Negotiated Price

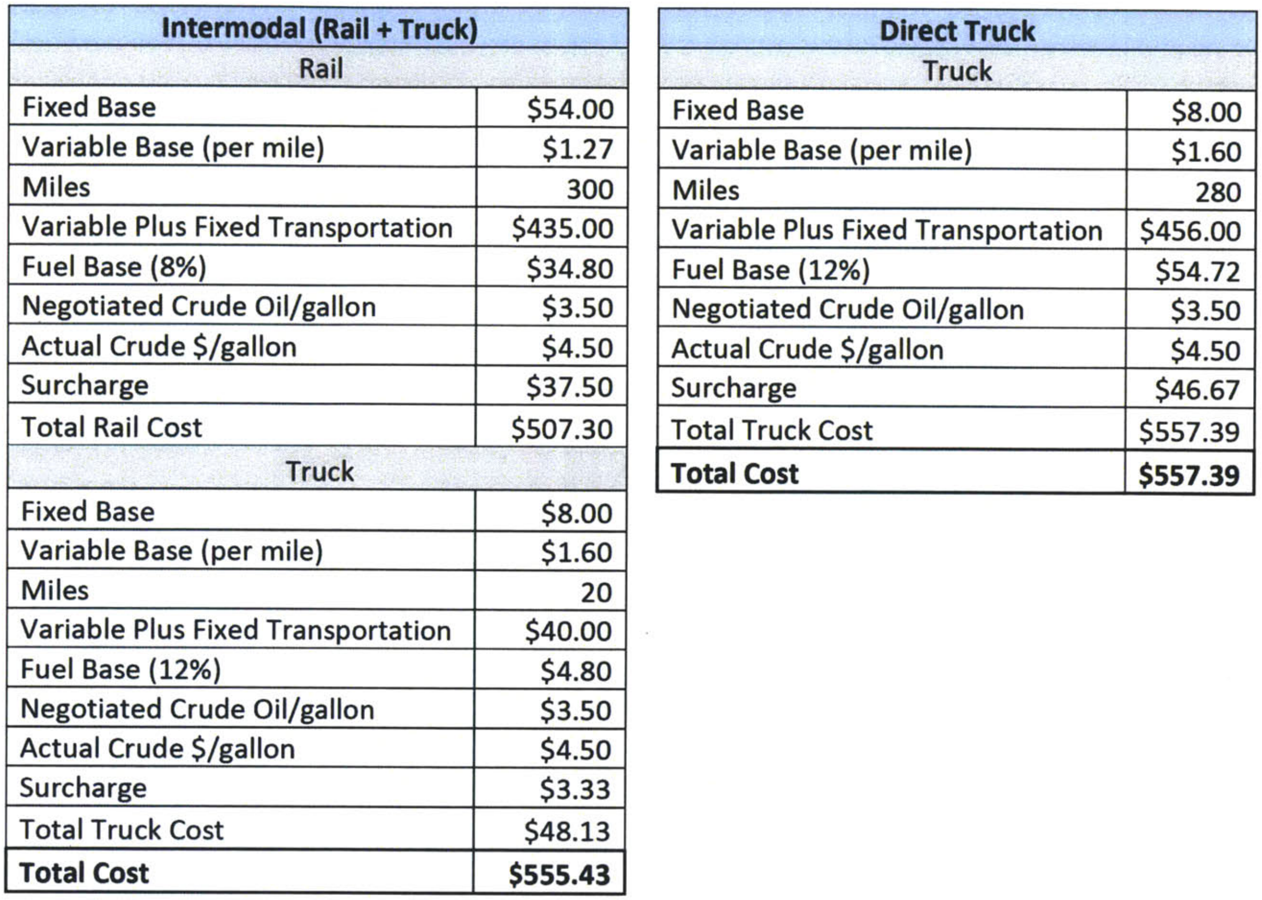


Intermodal (Rail + Truck)	
Rail	
Fixed Base	$54.00
Variable Base (per mile)	$1.27
Miles	300
Variable Plus Fixed Transportation	$435.00
Fuel Base (8%)	$34.80
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$3.50
Surcharge	$0.00
Total Rail Cost	$469.80
Truck	
Fixed Base	$8.00
Variable Base (per mile)	$1.60
Miles	20
Variable Plus Fixed Transportation	$40.00
Fuel Base (12%)	$4.80
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$3.50
Surcharge	$0.00
Total Truck Cost	$44.80
Total Cost	**$514.60**



Direct Truck	
Truck	
Fixed Base	$8.00
Variable Base (per mile)	$1.60
Miles	280
Variable Plus Fixed Transportation	$456.00
Fuel Base (12%)	$54.72
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$3.50
Surcharge	$0.00
Total Truck Cost	$510.72
Total Cost	**$510.72**

Figure 21: Intermodal vs Direct Truck with the Price of Crude Oil Above Negotiated Price

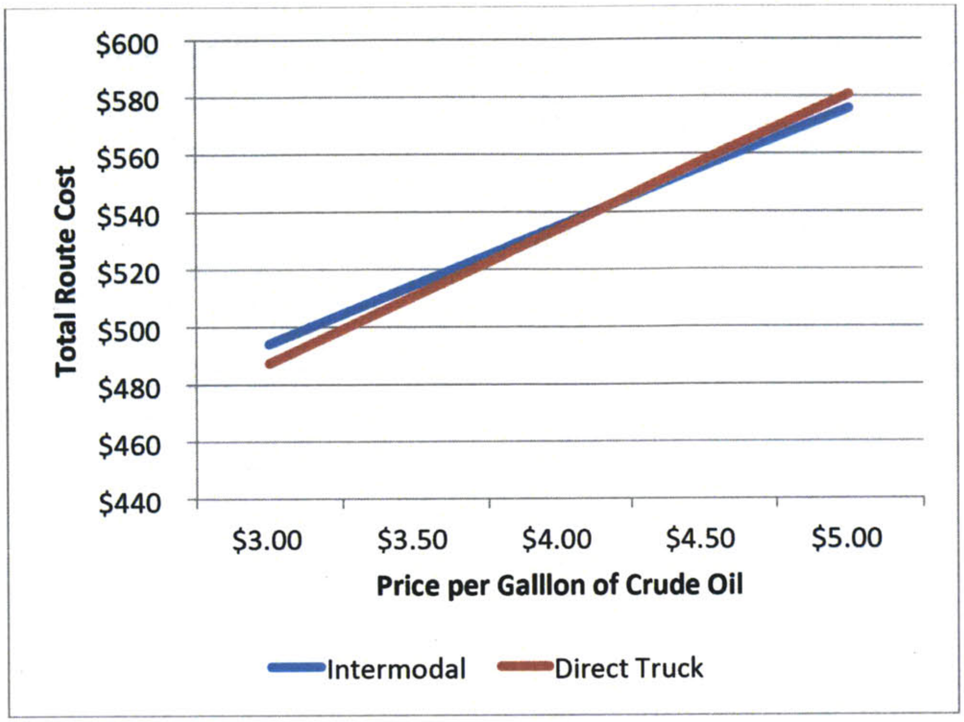


Intermodal (Rail + Truck)	
Rail	
Fixed Base	$54.00
Variable Base (per mile)	$1.27
Miles	300
Variable Plus Fixed Transportation	$435.00
Fuel Base (8%)	$34.80
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$4.50
Surcharge	$37.50
Total Rail Cost	$507.30
Truck	
Fixed Base	$8.00
Variable Base (per mile)	$1.60
Miles	20
Variable Plus Fixed Transportation	$40.00
Fuel Base (12%)	$4.80
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$4.50
Surcharge	$3.33
Total Truck Cost	$48.13
Total Cost	**$555.43**

Direct Truck	
Truck	
Fixed Base	$8.00
Variable Base (per mile)	$1.60
Miles	280
Variable Plus Fixed Transportation	$456.00
Fuel Base (12%)	$54.72
Negotiated Crude Oil/gallon	$3.50
Actual Crude $/gallon	$4.50
Surcharge	$46.67
Total Truck Cost	$557.39
Total Cost	**$557.39**

Using **Equation 18**, the breakeven price of crude oil can be determined. In the illustrative route above, the breakeven price of crude oil is $4.16 per gallon. The breakeven is illustrated where the intermodal and direct truck lines intersect in the graph in **Figure 22**. If the actual price of crude is below this value, NNA should route vehicles by direct truck. However, if the price of crude exceeds this value, it is cheaper to route by rail.

Figure 22: Cost of Intermodal and Direct Truck at Various Fuel Prices



Although the equations are useful in determining the breakeven for a single route, it is cumbersome for a large network with many products, origins, destinations, and interchanges. The sensitivity to fuel prices could be more easily solved in large networks through scenario analysis within supply chain software such as i2. Scenario analysis can be conducted by running the model at various fuel prices and finding the price where routes change from one mode of transportation to another. Using the results of the analysis, NNA can build a contingency plan. Because the network solution changes with the price of fuel, rather than have a single stagnant network, NNA can change its routing as the price of fuel changes. The information on the dynamic routing would be communicated to the carriers so that the carriers would know that if price of fuel is above a certain level, an alternative network design will be used.

PART 6: Conclusion and Next Steps

This project was an effort to understand the current distribution optimization model performed for Nissan North America by its third party logistics provider. In doing so, the goal was to find opportunities for improvement, which would reduce logistics costs at NNA. Although the details of the saving cannot be disclosed due to confidentiality, in total, the opportunities discovered could save NNA over ten million dollars if implemented. This reduction only touches the surface of the opportunity available to NNA. Further cost reduction could occur through further analysis, using the guiding improvement principles addressed in this paper:

1. **Increased flexibility will yield significant cost savings.** Finding opportunities to relax constraints or add more alternative routes to the network will create more opportunity for optimization and result in lower costs.
2. **Optimizing on "total landed cost" will ensure lowest cost solution.** Ensuring that proper costs are included in the objective function is critical to achieving the lowest cost solution. Ignoring inventory, storage costs, and damages, and simply focusing on transportation costs can be costly.
3. **Understanding network sensitivities can create a more responsive supply chain.** Using supply chain software proactively to understand the sensitivity of the model inputs can help the Company better understand the effect of rate increases, fuel price fluctuations, or even environmental disasters on the network. This information will be useful in carrier negotiations and will increase flexibility in responding to an emergency.

These principles are applicable to distribution networks in any industry. The first step in containing logistics costs is to understand the mathematics behind the network optimization model. The model inputs tend to be obscured if a model has been in use for several years or if it is an outsourced function. Understanding both the mathematical and structural constraints in the model, as well as their origins, will help to find ways to relax them and to increase model flexibility. In particular, a Company should understand the cost of constraint relaxation versus the benefit it will gain from lower network costs. Additionally, understanding the model inputs would allow for a deeper understanding of the costs included in the model objective function. Understanding cost tradeoffs outside of direct transportation costs can increase overall cash flow. Finally, running scenario analyses on each of the inputs (costs and constraints) will create an understanding of the sensitivity of the network to each of these inputs and create a more responsive network and better prepare the Company for negotiations with carriers.

The next step for NNA is to implement the cost cutting measures identified, not only within the model but in their actual network. Using the output from the more robust model, Nissan North America should work with its 3PL and its carriers to change existing routing to that of the model output. It should run the model regularly, so that the routing can change dynamically with rates and fuel prices. It should also work with its information technology organization to allow for multiple routes per dealer and should work with its carriers to find ways to increase capacity out of Veracruz or open alternative railheads or ports. Cost savings from an improved strategy cannot be realized until the strategy is implemented.

Another step for NNA is to use optimization software to further optimize the supply chain by using it for planning purposes earlier in the supply chain decision-making process.

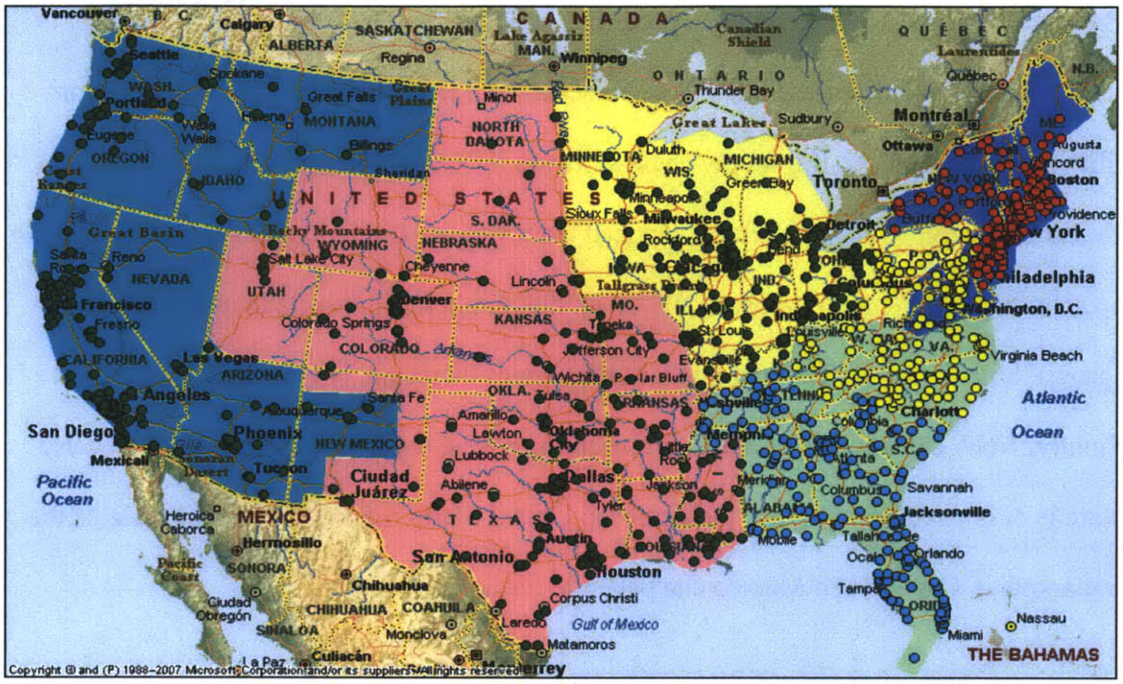
Currently, NNA optimizes its distribution routing around its existing network. However, by using the software prior to a new model launch, NNA can use it to determine optimum facility locations, inventory policy, production allocation among plants, and sourcing. For instance, the Altima is currently a dual sourced product, produced in both Smyrna, TN and Canton, MS. However, production quantities are fixed in each facility and the dealers that are serviced from each facility are also fixed. Using supply chain software, NNA can optimize how much to produce at each facility, which dealers are serviced from which plant, and the distribution routing simultaneously to yield the lowest cost to NNA. As the number of products that will be dual sourced grows, holistic supply chain optimization becomes increasingly important.

Finally, NNA can also expand the optimization process to its other markets. Currently, the software is only used regularly for the domestic United States market. Expanding use of the model to markets in Canada and Mexico can generate further savings.

PART 7: Appendix

Appendix 1: Nissan and Infiniti Dealer Locations [15]

Colors represent NNA sales regions.



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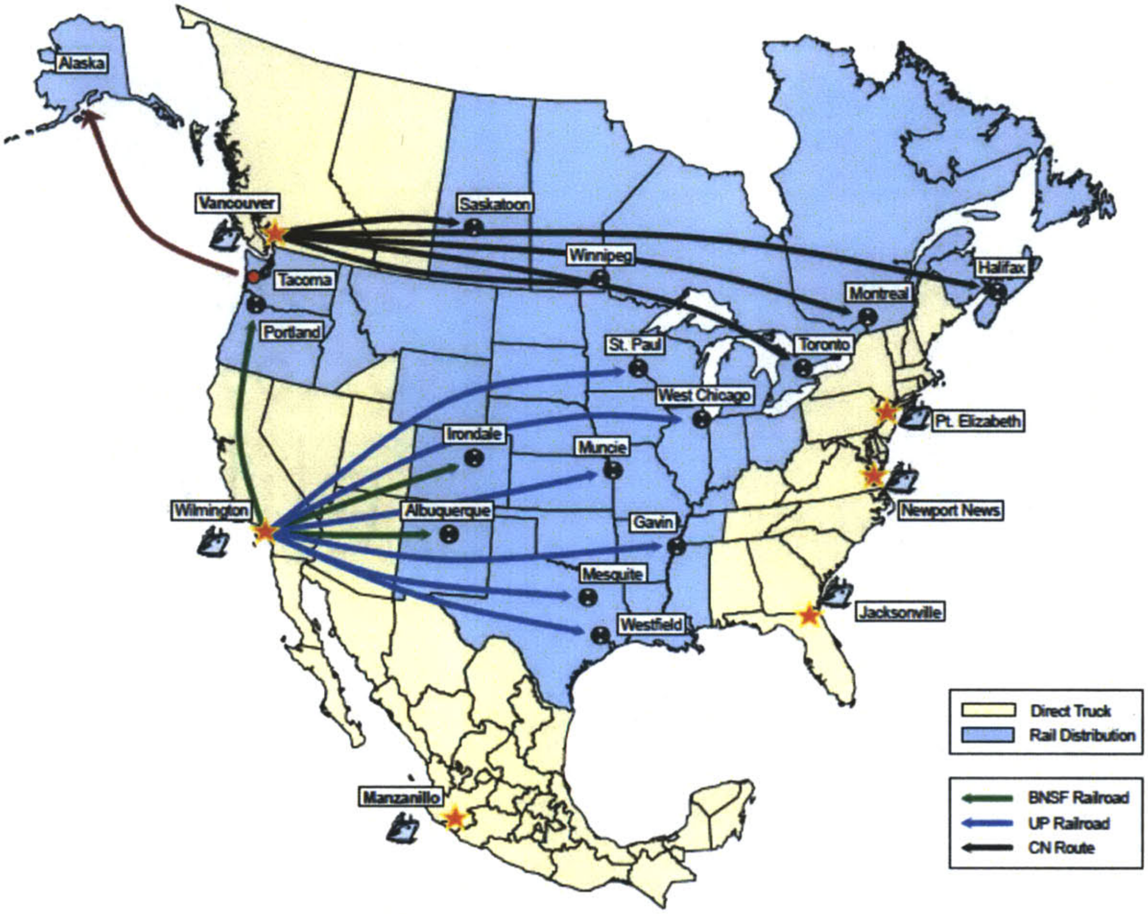
Appendix 2: Images of Tri-level, Bi-level, and Automax Railcars [15]

Tri-level

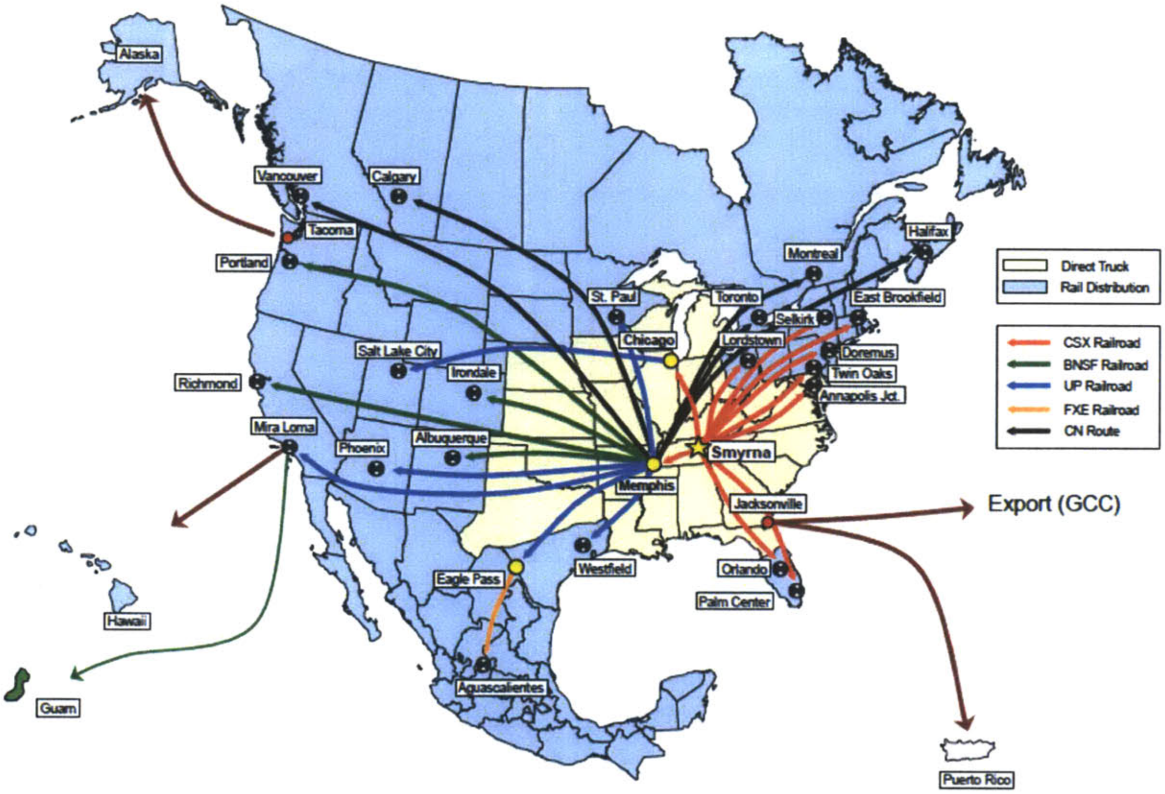
Bi-level

Automax

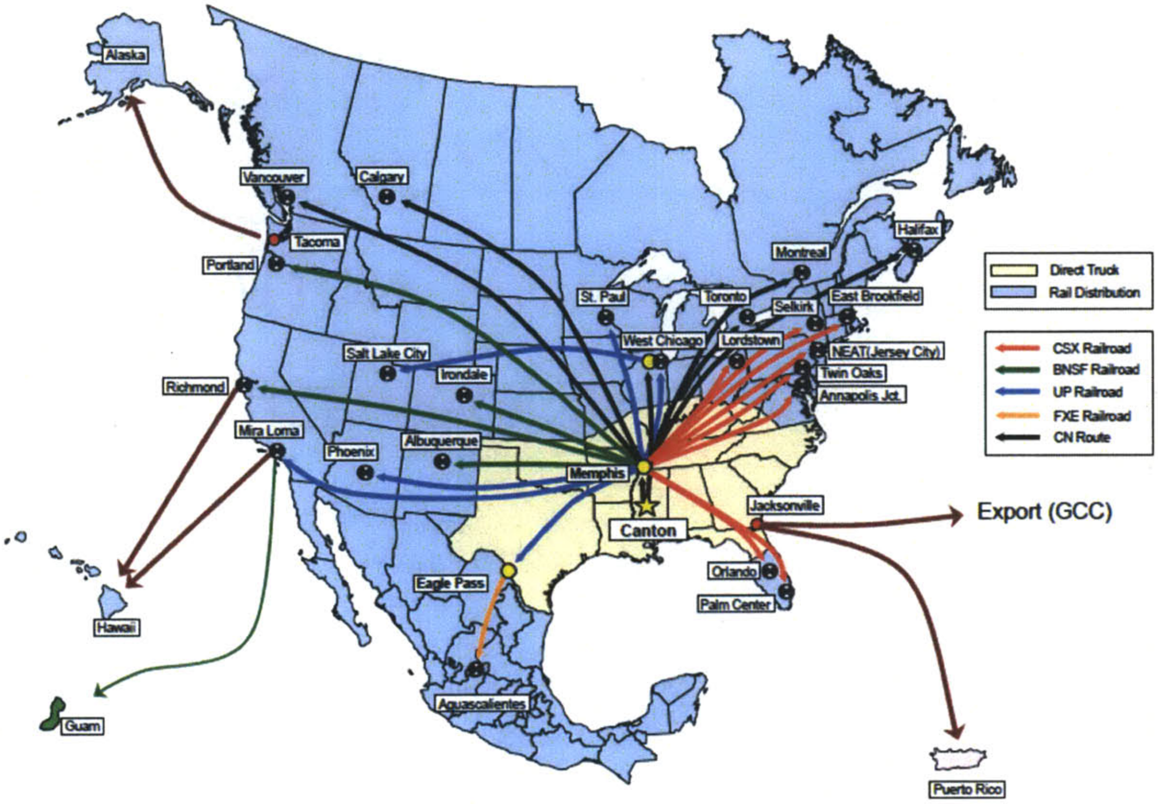
Appendix 3: NML Routing (Japan) [15]



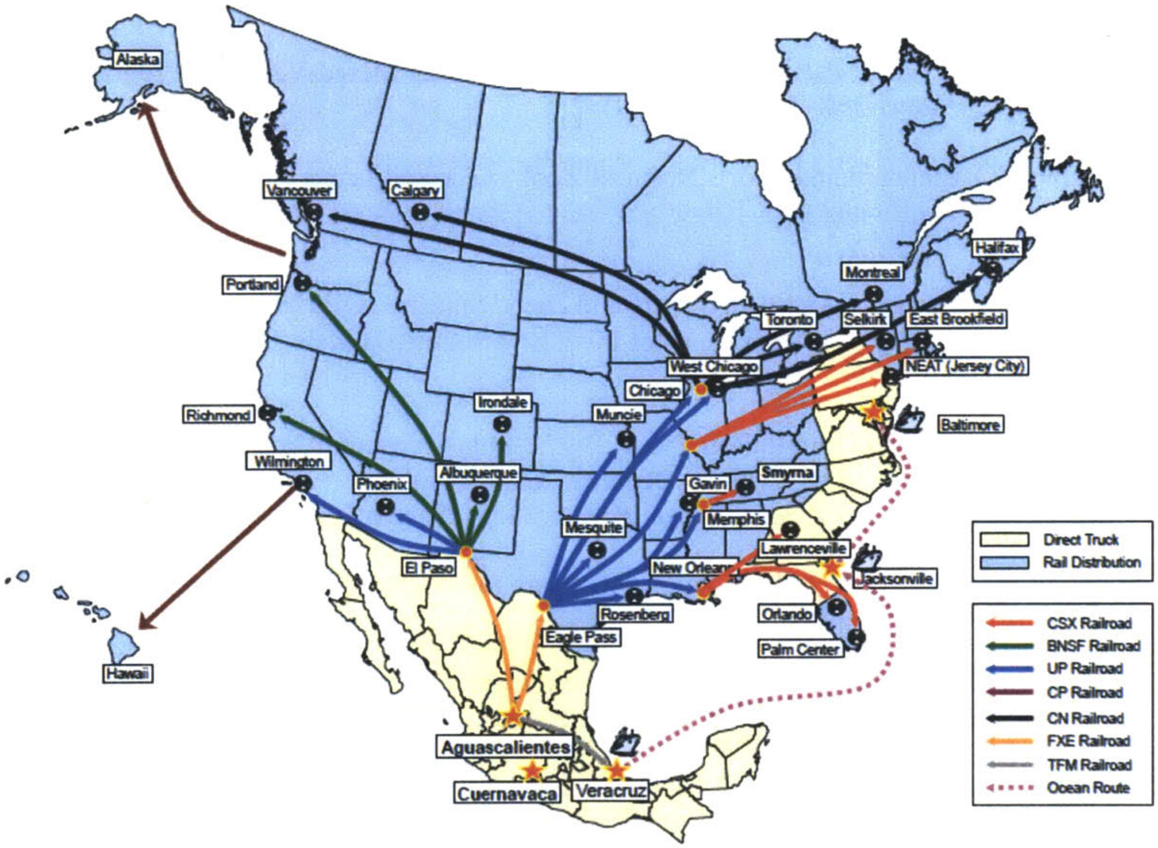
Appendix 4: NNA-S Routing (Smyrna) [15]



Appendix 5: NNA-C Routing (Canton) [15]



Appendix 6: NMEX Routing (Mexico) [15]



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