Inbound Freight Consolidation: A Simulation Model to Evaluate Consolidation Rules

by

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Submitted to the Engineering Systems Division in
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Abstract

In logistics, freight can be consolidated over time (temporally) or over space (spatially). This thesis presents a simulation model to evaluate temporal and spatial consolidation rules. The model is the result of a research project to analyze freight consolidation options for a large industrial company. The research project focused on the company's freight imported from China to the US, and the model presented in the thesis is structured to represent a typical import logistics network.

The results section of the thesis presents a method for evaluating consolidation rules. The results recommend temporal consolidation of two weeks at the origin port and temporal consolidation of less than one week at the factory for the company's shipments from China to the US. This consolidation policy offers total network cost savings of 24% over the base case, an immediate ship policy.

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Title: Research Associate

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1. Introduction

A graduate student mails letters home to his mother everyday. The problem is he simply can't afford the post. For this reason he has decided to implement a consolidation program to save money on the stamps, but he is still analyzing what consolidation method will allow him to save money while still maintaining the letter's timely value.

The graduate student has two options for consolidation: temporally consolidation (over time) or spatial consolidation (over space). To consolidate the letters temporally, he holds today's letter for shipment with tomorrow's. By waiting one day, he is able to ship two letters in one envelope and save the cost of one stamp. To consolidate spatially, he meets his sister (who also mails letters home to mom daily) at the post office, where they can combine letters to ship in one envelope, again saving the cost of one stamp.

The purpose of this thesis is to present a model that evaluates rules for spatial and temporal consolidation. If the graduate student waits to send letters home to mom, how long should he wait? If he and his sister decide to meet at the post office, which post office should they meet at?

The case of sending letters home to mom is not far removed from the choices that many company's face today in shipping. This thesis is the result of a sponsored research project to analyze freight consolidation options for a large industrial company. The simulation model presented in this thesis is the direct result of the research project.

First, the thesis will introduce the industrial company's current situation. Second, the thesis will present the simulation model. Finally, the results of the research project will be highlighted and discussed. But before we get there, let's first review some of the benefits and costs of consolidation.

1.1 Benefits of Consolidation

1.1.1 Returns to Scale: Freight logistics exhibit significant returns to scale. For instance, UPS charges about $15 to ship a 1-pound package overnight, but only about $30 to ship a 15-pound package overnight. The per unit freight rate for the 1-pound package is about $15/lb, while the per unit freight rate for the 15-pound shipment is about $2/lb. Although this is an extreme example, returns to scale exist throughout freight logistics. Whether comparing less-than-truckload (LTL) to truckload (TL), less-than-container (LCL) to full container (FCL), or 10,000 kg barges to 100,000kg barges; per unit freight rates decrease as the shipment size increases.

1.1.2 Reduction of Fixed Costs: Consolidation reduces the total # of shipments, which in turn reduces total fixed costs. Regardless of the situation, companies incur fixed costs throughout the shipping process. In the letter to mom example, there is a fixed cost every time the student walks to the post office. In the case of UPS, it takes a fixed amount of time to fill out a UPS delivery form. In the case of an import network, a customs broker receives fixed payments independent of the shipment size. Consolidation reduces the number of shipments, thereby reducing the number of times that you have to walk to the post office, fill out a UPS form, or pay fixed brokerage charges.

1.1.3 Speed and Reliability: Consolidated shipments can exhibit increased speed and reliability. For instance, full truckload (FT) is generally faster and more reliable (transportation time variance is less) than less-than-truckload (LTL) shipments. Likewise, processing at US ports (the time from arrival until availability) is general faster and more reliable for full container shipments (FCL) than for less-than-container (LCL) shipments. Moreover, goods shipped by FT or FCL are touched less and are less prone to damage than goods shipped by LTL or LCL.

1.2 Costs of Consolidation

1.2.1 Time: Despite all of its benefits, consolidate is not without cost. Temporal consolidation consumes time and cost savings from consolidation must be balanced against the value of time. The cost of transit time is directly related to the value of the goods in transit and the variability of the transit time.

In this model, transit time starts when the goods finish production and ends with the goods arrive at the DC. In contrast, transportation time (as discussed in 1.1.3) starts when the good leave point A and ends when the goods arrive at point B. Transportation time does not include the time waited at point A. Thus, although consolidated shipments exhibit increased speed and reliability in transportation time, this time savings is often lost in during the waiting process.

1.2.2 Distance: Spatial consolidation requires that goods travel a greater distance. In the case of sending letters home to mom, though the student and his sister both live in Boston, the post office nearest to his house is different from the post office nearest to her house. Spatial consolidation thus requires that one of them will have to travel farther than if they shipped individually. Increases in distance must be accounted for.

1.2.3 Coordination Costs: Finally, consolidation requires coordination and rules. If the student and his sister are going to meet at the post office, they need to coordinate the time and location to meet. Coordination takes time and effort. Systematic consolidation rules can help reduce coordination costs. For instance, the student and his sister could set a rule to meet at post office "A" at 3:00 pm every Wednesday. Nevertheless, analyzing the network to determine appropriate rules still takes time and effort.

2. Industry Case

The sponsor company for this thesis, a large industrial corporation, produces the majority of its products in Asia. The majority of these products are produced in China. For this reason, we decided to focus our research on consolidation options for the company's inbound freight from China.

2.1 Operational Overview

According to interviews with the company's logistics manager, the company's suppliers and factories in China ship more of less when they feel it's appropriate. Shipments are sent directly from the factory to the DC with no option for consolidation the origin port or the destination port. According to our understanding, informal consolidation is in place at the factory, but consolidation of any type outside of the factory does not exist.

The company uses various transportation providers to ship goods from of China. The company plans to move all freight to one 3PL provider by year end. Of the providers that the company is considering, all have the capability to consolidate freight at the China Port and at the US Port.

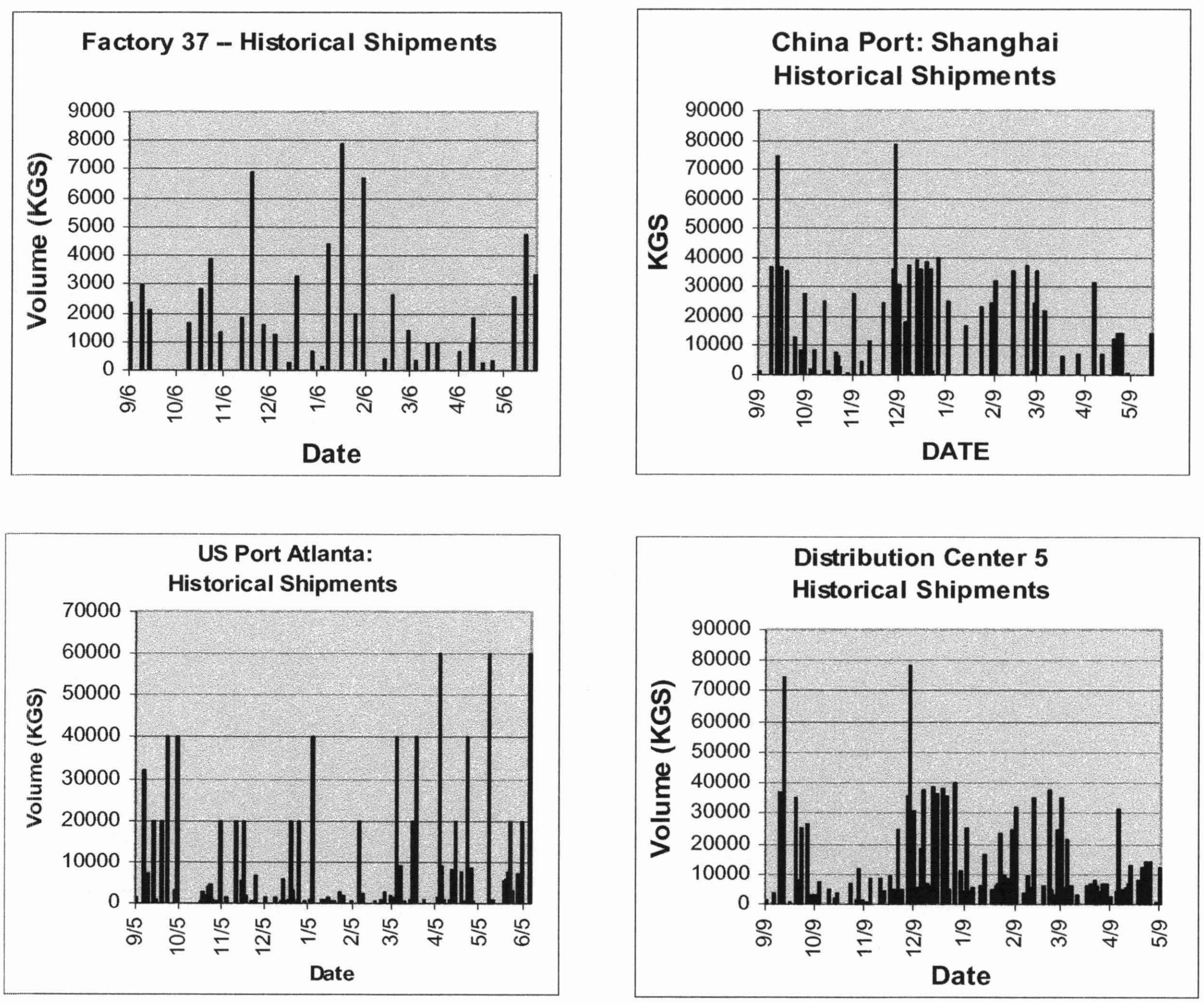
The freight being shipped is dense and industrial. Shipments "weigh out" rather than "volume out" and for this reason the data used for the research project is based on weight rather than volume.

Finally, most of company's distribution centers are engaged in light manufacturing (tooling, painting, kitting, and assembly). For this reason, the research project does not include the final customer. The DC is considered the final customer in the project.

2.2 Data Summary

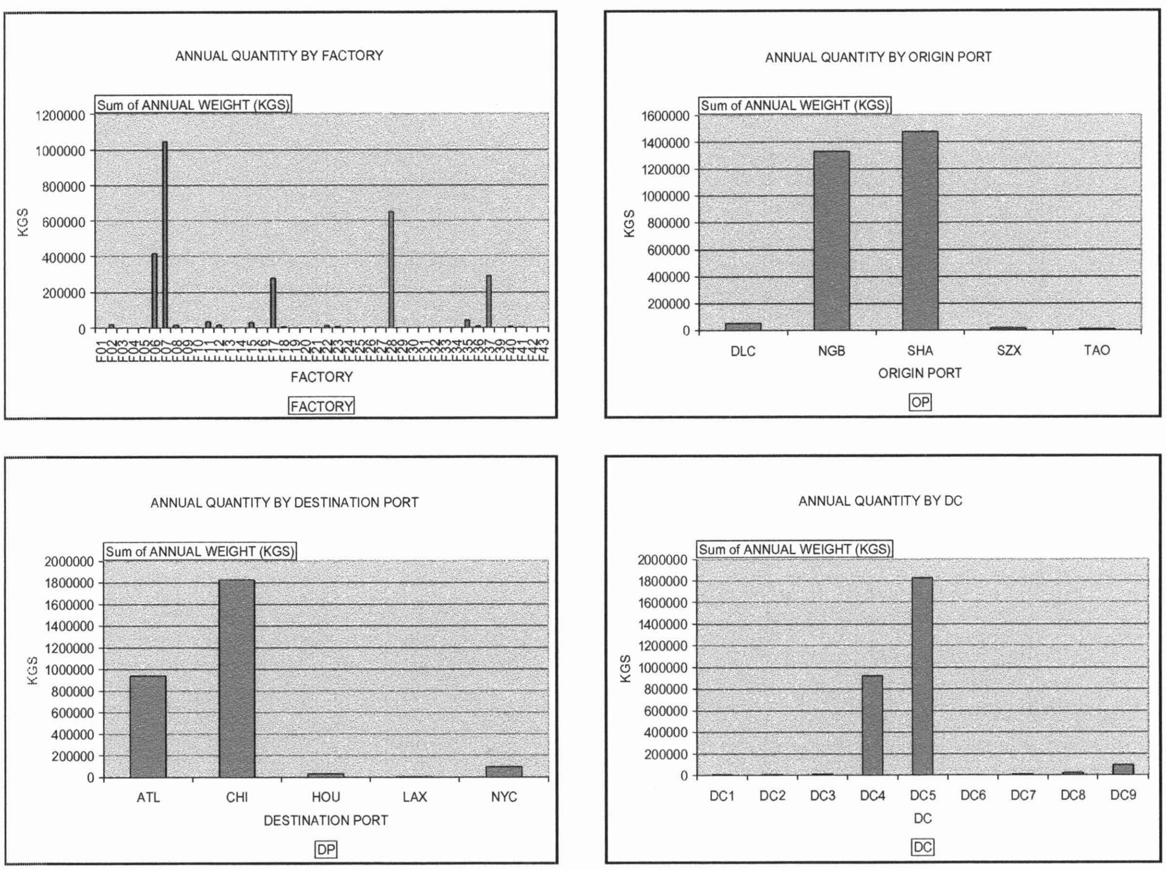
The simulation model that we will visit later requires volume, cost and time data for the entire network. Much of the project was spent compiling this data, but in the end, most of the data still suffered from lack of normalization and completeness. The volume, costs and time distributions in the model are made using best estimates from the data provided. Finally, although we found possible evidence for seasonality in the historical shipping data (see exhibit 2.1), the lack of complete data made it difficult to determine if low seasons were the result of missing data or low demand. The company's logistics manager noted that demand for the majority of the business is stable year round. The production output simulation in this thesis assumes no seasonality.

Exhibit 2.1: Samples of Historical Shipment Data



As we can see from Exhibit 2.2 below the company has approximately 50 manufacturing facilities or suppliers located in China (across all divisions), although most of the volume is dominated by five suppliers. The company has eight distribution centers in the US, although most of the volume from China is received by two DCs. The company exports primarily through two China ports (Ningbo and Shanghai) and imports primarily through two US ports (Chicago and Atlanta). Annual shipment weight from China to the US is approximately 3,000,000 KGS / Year.

Exhibit 2.2: Annual Volume (kgs)



3. Literature Review

Most of the research written on consolidation focuses on finding an optimal solution for a two or three node, steady state network. A four node network, with variable demand, variable transit times, and different modes of transportation, as presented in this thesis is more difficult to optimize. In order to maintain the realism of a complex model, while at the same time keeping simplicity in computation, we have chosen to use Monte Carlo simulation rather than optimization.

First, let's review the results from previous consolidation optimization studies. Considering that we were unable to find recent simulation studies published on consolidation, the results from optimization studies on consolidation will serve as a baseline to analyze the feasibility of the cost savings presented in the industry case results section. After we review these results, we will introduce guidelines for Monte Carlo simulation used in the framework for the model presented in this thesis.

3.1 Results from Previous Consolidation Studies

Buffa and Munn (1989) present the case of a commodity product shipped over a two node, one segment network. The study assumes that only one mode of transport is available, and the key notion of their model is that "shipping costs is based on freight rate, which is a function of shipping weight, which, in turn, is dependent on the cycle time for the reorder" (p. 370). In juxtaposition, the simulation model in this thesis assumes two types of transportation for each segment, but does not include the order cycle as a decision. Buffa and Munn use a recursive algorithm to solve for the optimal order cycle time, and they find a "9.2% reduction on the cost for the set where each item was ordered separately, and a 0.4% reduction on the cost for the set where all items were ordered together" (p. 374).

Centinka and Lee (2002) present an optimization model to minimize transportation and inventory costs over a two node, one segment network in "the case where the aggregate demand of the market area is constant and known per period" (p. 531) and transportation time is assumed to be negligible (p. 532). In contrast, the model in this thesis presents the case where demand is variable and transit time is significant. Centinka and Lee find that for the "uncapacitated problem the average cost savings in using the optimal policy, rather than the approximate policy is given by 3.4%. The maximum cost savings is 13.3% whereas the minimum cost savings is 0.27%" (p. 548).

Nass, Dekker, and Sonderen-Huisman (1997) focus on determining the optimal "cutoff order size" for "physical distribution management for a product company in Western Europe" (p. 1057). They considers the case of a three node network (factory, DC, customer) in which the factory has the option to ship direct to the customer or through a DC. In contrast, the model present in this thesis assumes that all shipments flow through each of the four nodes (factory, origin port, destination port, DC). There is no option to skip the origin port or the destination port. While Nass et al. focus on the optimal cutoff order, the model in this thesis looks to evaluate the effect of the consolidation cutoff value. In the case study presented by Nass et al., they find an optimal solution which recommends "an increase in delivery through a DC from 63-75%" and obtains "2% lower costs" (p. 1063).

Cost savings in the above research varies from a minimum of 0.27% to a maximum of 13.3%. As highlighted above, the networks in the research above are less complex than the network modeled in this thesis. Given that complexity drives costs, we expect the potential cost savings to be greater in the network at hand than in research found above.

3.2 Monte Carlo Simulation

Monte Carlo Simulations have been used for management decisions for well over 50 years (Malcom, 1960). Recently, new tools such as Genetic Algorithms and Markov Chain Monte Carlo have taken Monte Carlo to new heights. This thesis provides a showcase that with basic modern software (Excel), a 50-year-old simulation technique (Monte-Carlo) can still be used to create simple, customized, and effective simulations for management decisions.

The below guidelines from Geisler and Steger (1963) are an excellent reference for simulation design. If a simulation model doesn't have the majority of characteristics listed below, it's likely an inadequate representation of the system.

Exhibit 3.1: Guidelines for Logistic Systems Simulation

Systems Characteristics

1) They contain many interacting elements.
2) They contain elements affected by randomness, unpredictability, risk, etc.
3) They include activities whose performance is affected by time lags.
4) Logistics systems require resources, ie costs.
5) Logistics systems require policies, rules, and problem-solving capabilities for their operation.
6) Logistics systems employ information and data.
7) Logistics systems embody component organizations.
8) Logistics systems have mutual impacts with other systems without systems, such as combat commands, factories, and the like.

Source: Geisler (1963)

4. Simulation Model

This simulation model is designed to analyze consolidation options for inbound freight from China to the US. Although the model is focused on a specific country to country import network (China to the United States), it is applicable to any 4-node, 3-segment import network.

The 4 nodes in the model are:

1. Factory (F)
2. Origin Port (OP)
3. Destination Port (DP)
4. Distribution Center (DC)

The 3 segments in the model are:

1. Factory to Origin Port
2. Origin Port to Destination Port
3. Destination Port to Distribution Center

The model contains 5 main elements:

1. Spatial and Temporal Consolidation Rules
2. Production Output and Transit Time Simulations
3. Constraints
4. Fixed and Variable Transit Costs
5. Cost of Transit Time

The key to this model is its use of spatial and temporal consolidation rules. These rules determine how freight flows through the network. First, we will review spatial and temporal consolidation rules. Second, we will explore production output and transit time simulations. Third, we will look at the model's constraints.

After reviewing these first three elements, we will stop to examine a diagram that shows how these elements interact to make up the physical structure of the model. Finally, we will review the financial structure of the model: fixed and variable costs and the cost of transit time.

4.1 Spatial Consolidation Rules

Spatial Consolidation Rules determine the route freight follows in the network. In the model each factory is linked to a primary origin port and a consolidation origin port. Likewise, each distribution center is linked to a primary destination port and a consolidation destination port. Depending on spatial consolidation rules factories either ship to their primary origin port or to their consolidation origin port, while distribution centers either receive from their primary destination port or from their consolidation origin port.

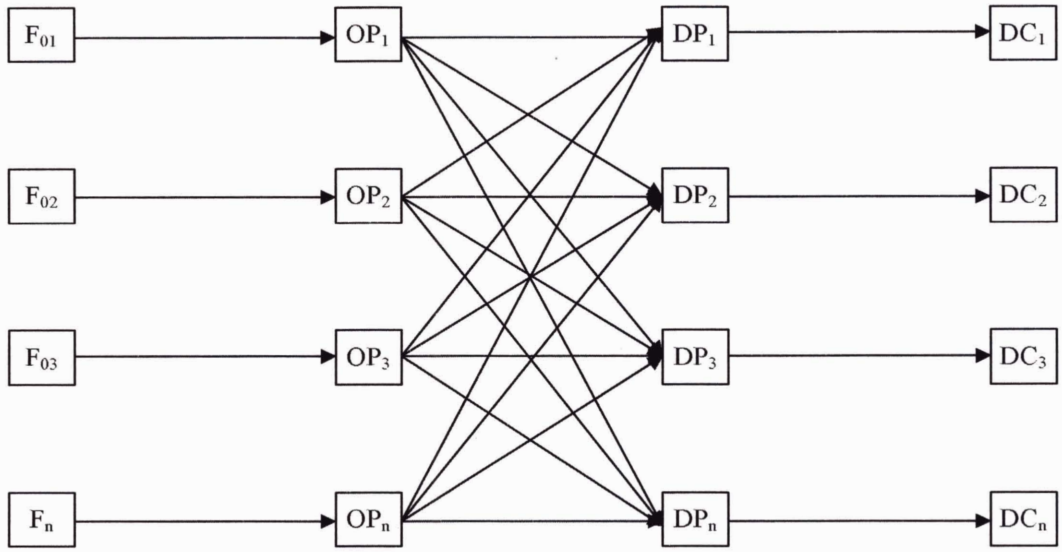
This thesis will examine 4 spatial consolidation cases: Direct Shipment, Origin Port Consolidation, Destination Port Consolidation, and Origin and Destination Port Consolidation. . The consolidation logic for each case is listed in the table below.

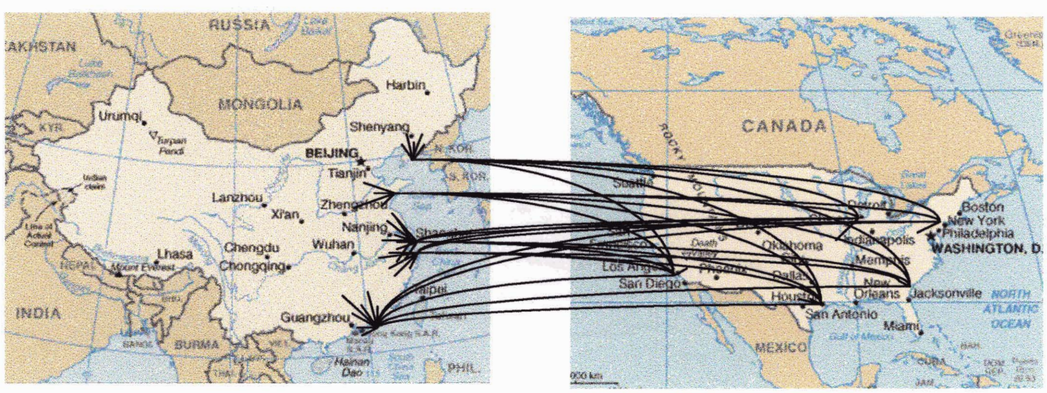
Exhibit 4.1: Spatial Consolidation Cases

Case Abbreviation	Case Name	Rule 1: Origin Port Consolidation?	Rule 2: Destination Port Consolidation?
FACT	Factory Consolidation	No	No
ORIG	Origin Port Consolidation	Yes	No
DEST	Destination Port Consolidation	No	Yes
FULL	Origin and Destination Port Consolidation	Yes	Yes

The above case abbreviations will be used throughout the paper. To get a better feeling for these four spatial consolidation cases, the networks diagrams for each of the four cases. A description of each case is listed below the case network diagrams.

Exhibit 4.2: Factory Consolidation (FACT)



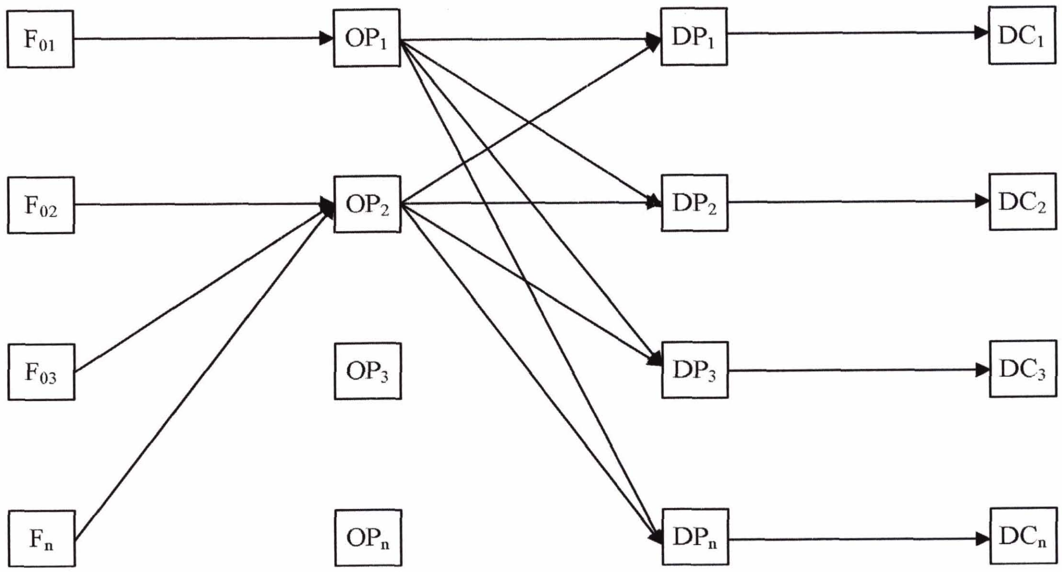


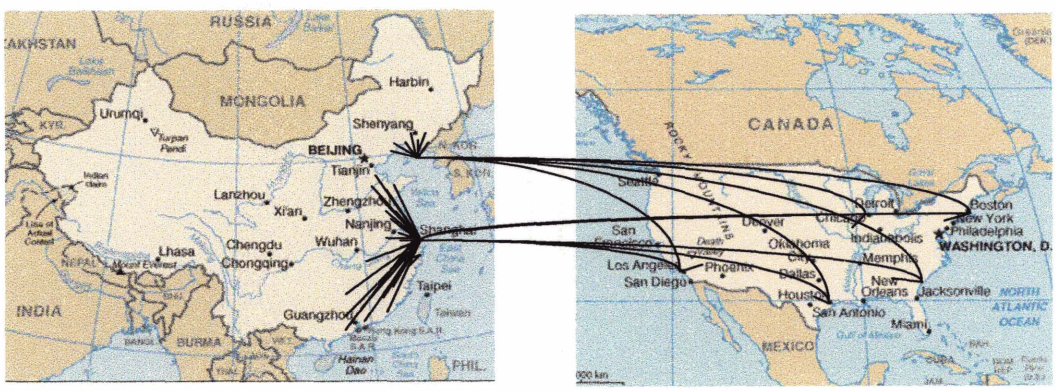
Map Source: CIA

Under direct shipment, there is no spatial consolidation. Factories ship by truck to the China port closest to them. From the China port goods are shipped by ocean to the US port closest to the distribution center. The goods are picked up at the US port are trucked to the distribution center. Factory consolidation is analogous to the student and his sister shipping from independent post offices.

The China ports from the top down: Dalian (DLC), Qingdao (TAO), Shanghai (SHA), Ningbo (NGB), Shenzhen (SZX). US Ports: Los Angeles (LAX), Houston (HOU), Chicago (CHI), Atlanta (ATL), New York (NYC).

Exhibit 4.3: Origin Port Consolidation (ORIG)

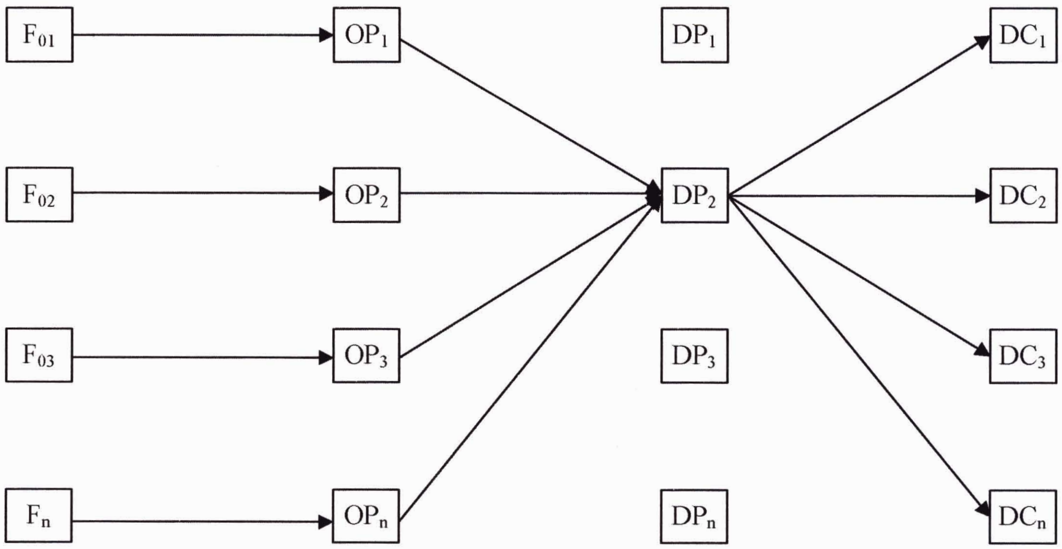


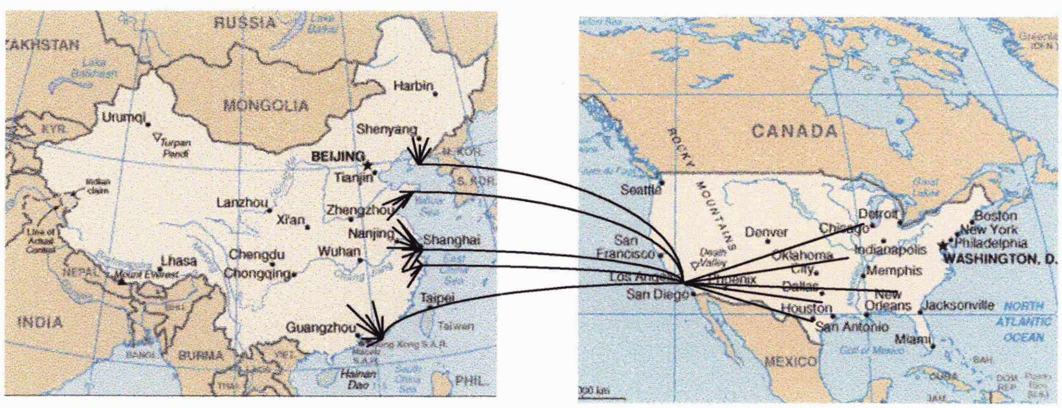


Map Source: CIA

Under origin port consolidation, factories ship by truck to their assigned consolidation port (in this case, Shanghai). From Shanghai, the goods are shipped by ocean to the US port closest to final distribution center. The goods are then picked up at the US port and trucked to the distribution center. Origin port consolidation is analogous to the graduate student and his sister meeting at the post office. Please note, as seen in the diagram above, that due to the feasibility of long distance trucking in China factories in northern China do not consolidate in Shanghai.

Exhibit 4.4: Destination Port Consolidation (DEST)

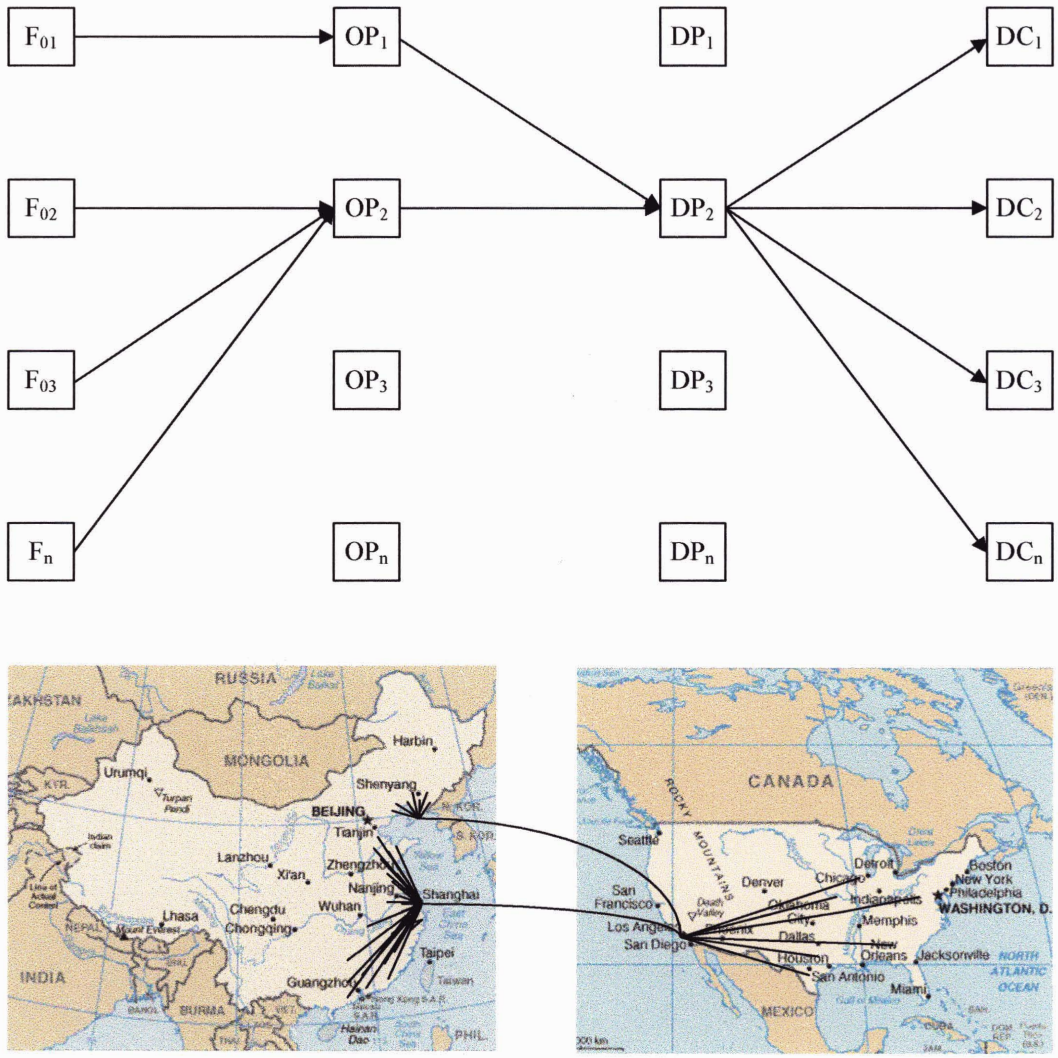




Map Source: CIA

Under destination port consolidation, factories ship by truck to the closest China port. From the China port goods are shipped by ocean to the assigned US consolidation port, in this case Los Angeles. From LA, goods are shipped by long haul truck to the distribution center. Destination port consolidation is analogous to the student and his sister shipping large packages independently to their mother, who then distributes the contents of the package to aunts, uncles, and grandparents who live in the area.

Exhibit 4.5: Origin Port and Destination Port Consolidation (FULL)



Map Source: CIA

Under full consolidation, factories ship by truck to their assigned China consolidation port. From the China port, goods are shipped by ocean to the assigned US consolidation port. From the US consolidation port, goods are shipped by long haul truck to the distribution center. Full consolidation is thus a combination of China port and US port consolidation. Full consolidation is analogous to the graduate student and his sister meeting at the post office to ship one large package to their mother, who then distributes the contents of the package to aunts, uncles, and grandparents who live in the area.

4.2 Temporal Consolidation Rules

Regardless of the spatial consolidation rules set, we always have the option to wait. Temporal consolidation rules determine:

1. Max Wait Time: How long we are willing to wait?
2. Cutoff Value: What we are waiting for?

For example, we can set temporal consolidation rules so that the factory ships to the origin port only if:

1. Any factory inventory is older than 7 days, or
2. The factory inventory is greater than 10000kgs.

In this case the factory cutoff value is 10000kgs, while the factory max wait time is 7 days.

The model is designed to evaluate temporal consolidation rules at the Factory, Origin Port, and Destination Port. The Industry Case Results section we will compare a range temporal consolidation rules for each of the four spatial consolidation cases diagramed above.

4.3 Production Output Simulation

In the model, production output contains the following values: Factory, Quantity, Date, and Distribution Center. In our current case historical shipment data is inadequate to estimate production output, as informal consolidation is already in place at the factory. As the sponsor company was unable to provide data on order placement or production output, we estimate the average order size as ½ of the shipment size from historical data. In the production output simulation, quantity is based on a normal distribution (mean = average order size, standard deviation = 20% of the average order size). All figures in the model are restricted to positive numbers. Production output simulation inputs are referenced from the factory to DC table (Exhibit A.6). A sample of the production output simulation is found in the exhibit below.

Exhibit 4.6: Production Output Simulation (sample)

FACTORY	DC	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan	6-Jan
F01	DC9	0	0	0	0	0	0
F02	DC5	0	0	0	0	0	0
F03	DC3	0	0	0	0	0	0
F03	DC8	0	0	0	0	0	0
F04	DC1	0	70	0	0	0	0
F04	DC8	0	0	0	1041	0	0
F05	DC9	0	0	0	0	0	0
F06	DC5	0	0	0	13327	0	0
F07	DC5	0	0	0	0	0	0
F08	DC4	0	0	0	23	0	0
F08	DC9	0	0	0	0	20	0
F09	DC5	0	0	0	0	0	0
F10	DC8	0	0	0	0	0	0
F11	DC5	0	0	0	0	0	0
F12	DC1	0	0	0	0	0	0

The above simulation sample can be read as follows:

January 2: 70 kgs finish production at factory F04 and are ready for shipment to DC1.

January 4: 1041 kgs finish production at factory F04 and are ready for shipment to DC8; 13327 kgs finish production at Factory F06 and are ready for shipment to DC5…

4.4 Transit Time Simulation

4.4.1 Factory to Origin Port: The model assumes that factory to origin port shipments take one day and exhibit zero variance in transit time. Most of the factories used by the sponsor company are located near the coast of China, within 3-4 hours of their primary port. The assumption that each factory to origin port shipment takes 1 day and exhibits zero variance is reasonable for shipments to the primary port. One the other hand, the distance from the factory to the consolidation port is father away, and the assumption of zero variance on transit time to the consolidation port is more tenuous. In an effort to keep the size of the model manageable we have left out the transit time simulation for the factory to origin port transit, and the assumption made to avoid this extra simulation should be noted.

4.4.2 Origin Port to Destination Port: Based on limited data from the sponsor company, FCL and LCL transit time distributions are estimated for each origin port to destination port lane. Time is measure from origin port departure to destination port arrival and does not include customs clearance or availability processing. FCL and LCL transit time distributions are referenced from the origin port to destination port table (Exhibit A.3). A sample of the production output simulation is found in the exhibit below. Notice that simulation values only return if a shipment has been made. If no shipment is made, the simulation returns a transit time of zero.

Exhibit 4.7: Port to Port Transit Simulation (sample)

LANE		7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb
OP1	DP1	0	0	0	0	0	0
OP1	DP2	0	0	0	0	0	0
OP1	DP3	0	0	0	0	0	0
OP1	DP4	0	0	0	0	0	0
OP1	DP5	0	0	0	0	0	0
OP2	DP1	0	0	0	0	23	0
OP2	DP2	0	0	0	0	0	0
OP2	DP3	0	0	0	0	0	0
OP2	DP4	0	0	0	0	0	0
OP2	DP5	0	0	0	0	0	0
OP3	DP1	0	0	0	0	0	0
OP3	DP2	0	0	0	0	0	0
OP3	DP3	0	0	0	0	0	0
OP3	DP4	29	0	0	0	0	0
OP3	DP5	0	0	0	25	0	0

The above simulation sample can be read as follows:

February 7: A shipment is made from origin port 3 (OP3) to destination port 4 (DP4). This shipment takes 29 days.

February 10: A shipment is made from origin port 3 (OP3) to destination port 4 (DP5). This shipment takes 25 days.

4.4.3 Destination Port: FCL and LCL customs clearance and availability processing time distributions are estimated for each destination port. Time is measured from destination port arrival to freight availability. The estimated customs clearance and availability processing distributions are referenced from the destination port table (Exhibit A.5). A sample of the customs clearance and availability processing simulation is found below.

Exhibit 4.8: Customs and Freight Release Simulation (sample)

LANE		7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb
OP1	DP1	0	0	0	0	0	0	0
OP1	DP2	0	0	0	0	0	0	0
OP1	DP3	0	0	0	0	0	0	0
OP1	DP4	0	0	0	0	0	0	0
OP1	DP5	0	0	0	0	0	0	0
OP2	DP1	0	0	0	0	3	0	0
OP2	DP2	0	0	0	0	0	0	0
OP2	DP3	0	0	0	0	0	0	0
OP2	DP4	0	0	0	0	0	0	0
OP2	DP5	0	0	0	0	0	0	0
OP3	DP1	0	0	0	0	0	0	0
OP3	DP2	0	0	0	0	0	0	0
OP3	DP3	0	0	0	0	0	0	0
OP3	DP4	4	0	0	0	0	0	0
OP3	DP5	0	0	0	5	0	0	4
OP4	DP1	0	0	0	0	0	0	0
OP4	DP2	0	0	0	0	0	0	0
OP4	DP3	0	0	0	0	0	0	0
OP4	DP4	0	0	0	0	0	0	0

The above simulation sample can be read as follows:

February 7: A shipment is made OP3 to DP4. This shipment takes arrives at DP4 (after allotted port to port transportation time) and takes 4 days for customs clearance and freight release.

February 10: A shipment is made OP3 to DP5. This shipment takes arrives at DP5 (after allotted port to port transportation time) and takes 5 days for customs clearance and freight release.

4.4.4 Destination Port to DC: FT and LTL transit time distributions are estimated for each destination port to DC lane. Time is measured from availability at destination port to arrival at DC. Estimated distributions are referenced from the destination port to DC table (Exhibit A.6). A sample of the destination port to DC truck time simulation is found below.

Exhibit 4.9: Inland Truck Time Simulation (sample)

Lane		19-Feb	20-Feb	21-Feb	22-Feb	23-Feb	24-Feb
DP1	DC3	0	0	0	0	0	0
DP1	DC4	0	1	0	0	1	0
DP1	DC2	0	0	0	0	0	0
DP2	DC5	0	0	0	3	0	0
DP3	DC6	0	0	0	0	0	0
DP3	DC7	0	0	0	0	0	0
DP3	DC8	0	0	0	0	0	0
DP4	DC1	0	0	0	0	0	0
DP5	DC9	2	0	0	1	0	0

The above simulation sample can be read as follows:

February 19: A shipment is available for pick up at destination port 5 (DP5) for shipment to DC9. The truck shipment from DP5 to DC9 takes 2 days.

February 20: A shipment is available for pick up at destination port 1 (DP1) for shipment to DC4. The truck shipment from DP1 to DC4 takes 1 days.

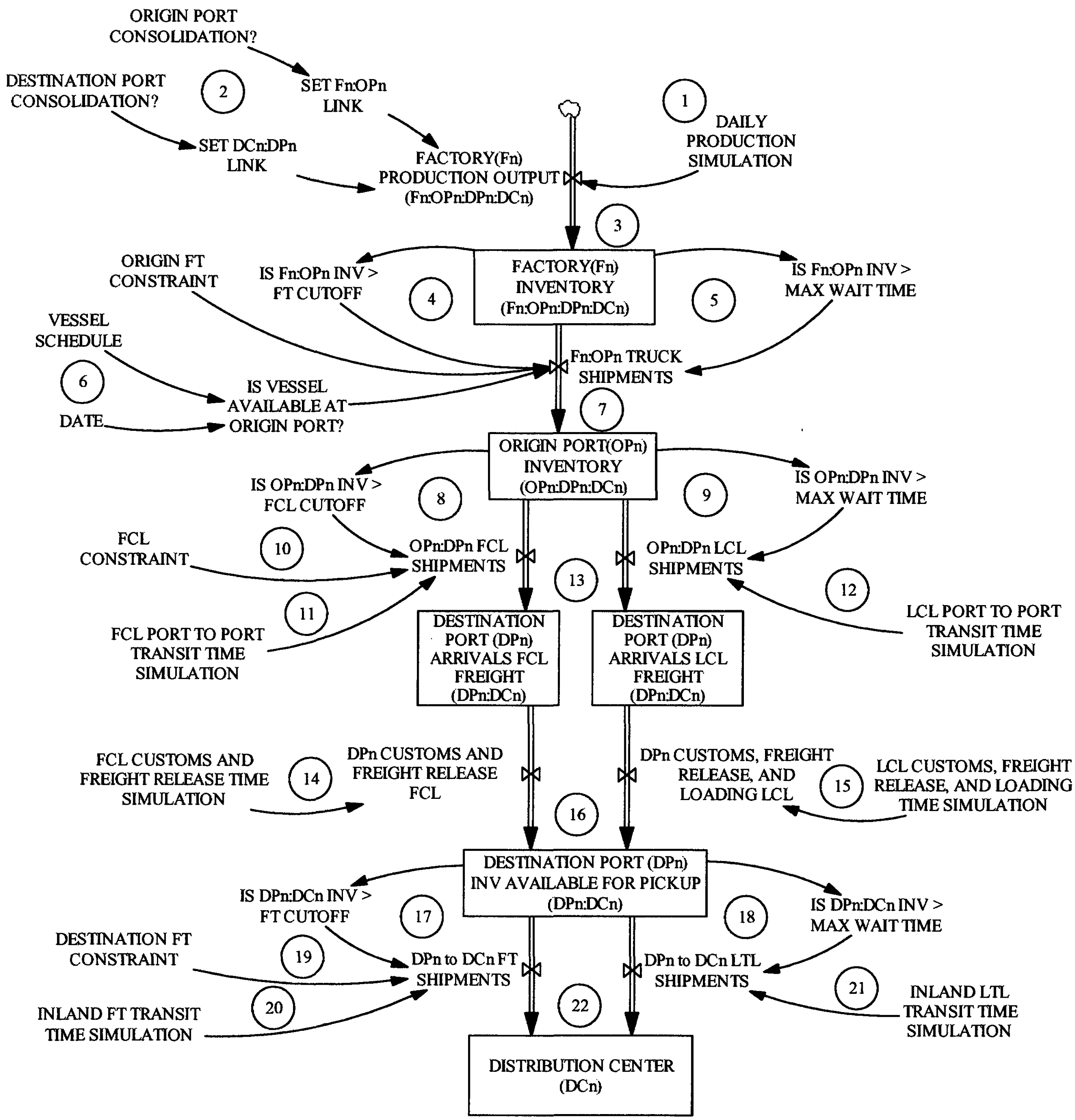
4.5 Constraints

4.5.1 Factory to Origin Port: Full truckload shipments are constrained by a maximum truckload weight (17000kgs). The model does not include truckload volume as a constraint, as the case at hand involves industrial freight which weighs out. The model assumes zero constraints on factor to origin port truck availability.

4.5.2 Origin Port to Destination Port: Ocean shipments are constrained by ocean vessel availability. Ocean vessel availability is based on a weekly schedule and is referenced from the origin port to destination port table (Exhibit A.3). The model assumes that factories have access to ocean vessel shipping schedules and thus only ship to the origin port if a vessel is available. Full container shipments are constrained by a maximum container weight (17000kgs). The model does not include container volume as a constraint, as the case at hand involves industrial freight which weighs out. Finally the model assumes that all freight is shipped by 20' containers.

4.5.3 Destination Port to DC: Destination full truckload shipments are constrained by maximum truckload weight. Considering that the case involves dense industrial freight which weighs out, to simplify the model, we do not include a maximum truckload volume constraint. The model also assumes zero constraints on destination port to DC truck availability.

Exhibit 4.10: Simulation Model Flowchart



4.6 Walk Through of the Simulation Model

The above diagram shows how goods flow from the factory to the distribution center. Let's walk through each of the step in the model:

1) Production output simulation releases quantities for each factory to DC lane by day.
2) Spatial consolidation rules set the factory to origin port and distribution center to destination port links. With the links set, the production output simulation now contains the quantity, date, factory, origin port, destination port, and distribution center for each output quantity.
3) Production output is stored in factory inventory according its origin port to destination port to distribution center lane.
4) Factory checks if inventory on hand is greater than full truck cutoff value.
5) Factory checks if inventory on hand is older than max wait time.
6) If 4 or 5 are true, factory checks if vessel is available at origin port.
7) If 6 is true, factory ships to the origin port and goods are stored at the origin port according to their destination port to distribution center lane.
8) 3PL checks if goods at origin port (for shipment to a specific destination port) are greater than the full container cutoff value.
9) 3PL checks to see if goods at origin port (for shipment to a specific destination port) are older than max wait time.
10) If 8 is true, 3PL ships up to the full container constraint.
11) If 8 is true, transit time simulation assigns a transit time for FCL shipment.
12) If 9 is true, transit time simulation assigns a transit time for LCL shipment.
13) After allotted transit time, FCL and LCL shipments arrive at destination port.
14) If FCL shipment has arrived, customs and freight release time simulation assigns time to availability for FCL shipment.
15) If LCL shipment has arrived, customs and freight release time simulation assigns time to availability for LCL shipment.
16) After allotted customs and freight release time goods are available for pickup.
17) 3PL checks if goods at destination port for shipment to a particular DC are greater than the full truck cutoff value.
18) 3PL checks if goods at destination port for shipment to a particular DC are older than the max wait time.
19) If 17 is true, 3PL ships up to full truck constraint.
20) If 17 is true, Destination Port to DC time simulation assigns full truck transit time.
21) If 18 is true, Destination Port to DC time simulation assigns less than truck transit time.
22) After allotted time for inland truck transit, LTL and FT shipments arrive at DC.

As we have seen from the walk through above, rules and simulations govern the flow of goods through the simulated network. In the model, simulations are based on historical time and output distribution. These distributions are considered fixed. Changing transportation time distributions or order output distributions are not decision variables in the model. The only decision variables are thus temporal and spatial consolidation rules.

The model's fixed and variable costs are based on cost drivers from the simulated network. The simulated network is based on the fixed simulation distributions and the decision variables, the temporal and spatial consolidation rules. The model's costs are divided into 1) fixed and variable transit costs and 2) transit time costs.

4.7 Fixed and Variable Transit Costs

The fixed and variable costs for each segment in the model (or node where applicable) are listed below.

4.7.1 Factory to Origin Port: For factory to origin port shipments, full truck is assumed to be the only method of transportation. The cost driver is the number of factory to origin port truck shipments. Origin truck prices are referenced from the factory to origin port table (Exhibit A.2). Although some factories are Ex-works and some are Ex-Country, the model includes truck costs for all factory to origin port shipments.

4.7.2 Origin Port to Destination Port: For origin port to destination port shipments, transportation options are restricted to full container and less-than-container ocean shipments.

The FCL cost driver is the number of origin port to destination port FCL shipments. The LCL cost driver is the weight shipped over each origin port to destination port lane by LCL. Port to Port LCL and FCL prices are referenced from the origin port to destination port table (Exhibit A.3).

Based on interviews with the logistics manager at the industrial company, most 3PL's used by company will hold freight in China for two weeks free of charge. Based on the situation, we restricted the max wait time to 14 days or less at the origin port. Accordingly, origin port storage charges are not included in the model.

4.7.3 Destination Port: Each FCL or LCL shipment, regardless of size is charged a fixed brokerage charge at the destination port. Based on interviews with the company's logistics manager, the company pays a flat fee for brokerage regardless of the port. We have set this fee at $200. The fixed brokerage charge is referenced from the destination port table (Exhibit A.5).

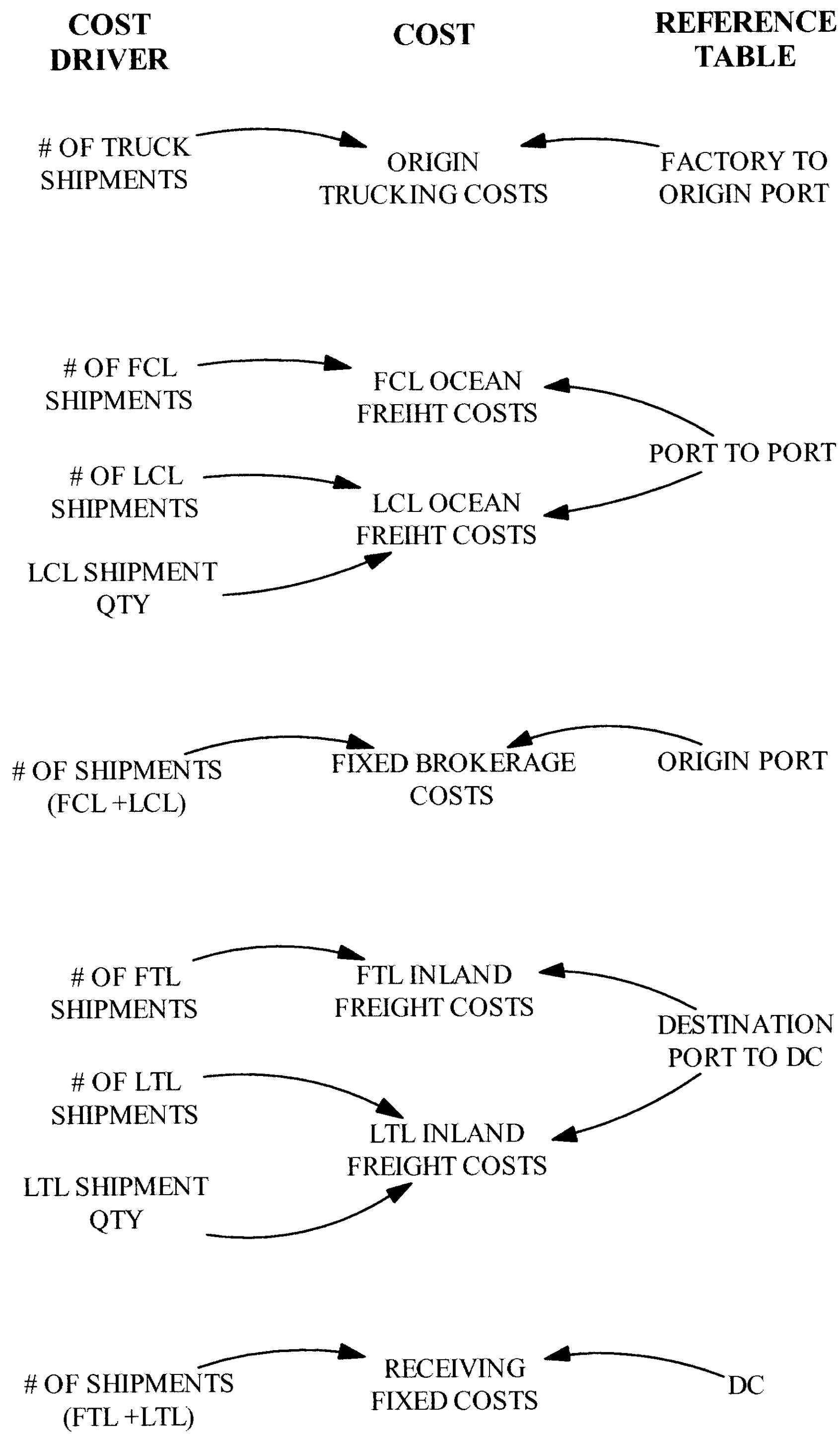
4.7.4 Destination Port to DC*:* For destination port to DC shipments, transportation options are restricted to FT and LTL shipments. The FT cost driver is the number of destination port to DC FT shipments. The LTL cost driver is the total weight shipped for each destination port to DC lane by LTL. LTL costing accounts for volume discounts. FTL and LTL costs are referenced from the destination port to DC table (Exhibit A.4).

Based on interviews with the company's logistics manager, most trucking companies used by the company will hold freight in their port warehouse for 1 week free of charge. It should be noted that cases in the results sections with destination port max wait times greater than 7 days, do not include the appropriate charges and should be viewed accordingly.

4.7.5 DC*:* Each FT or LTL shipment, regardless of size, is charged a fixed receiving charge at the DC. Based on discussions with the company's logistics manager, fixed receiving cost is estimated at $100 for each DC. Fixed receiving costs are referenced from the DC table (Exhibit A.6).

Exhibit 4.11 below summarizes the cost drivers and reference tables for all costs described above.

Exhibit 4.11: Cost Drivers and Reference Tables



4.8 Cost of Transit Time

Time is of the essence in supply chain management. The cost of transit time includes four main ingredients. The model accounts for the first two ingredients in the list below:

1. Pipeline Inventory Holding Cost
2. Safety Stock Inventory Holding Cost
3. Lost Sales due to Stockouts
4. Lost Potential for Sales Increase due to Quicker Time to Market

4.8.1 Pipeline Inventory Holding Cost depend on the average transit time, the average value of goods in transit, the company's holding cost rate, and the quantity shipped per year. The model uses the below equation to estimate pipeline inventory holding cost:

Pipeline Inv Cost = E[T]*v*r*Q/365

where
E[T] = average transit time
v = average value of goods / kg
r = company's holding cost rate
Q = quantity shipped per year

4.8.2 Safety Stock Inventory Holding Cost

Safety Stock Inventory Holding Cost is based on a required service level, the variance of demand, the expected demand, the average lead time of supply, the variance of the lead time of supply, the value of the goods, and company's holding cost rate. The model uses the below equations to estimate safety stock inventory holding cost:

Safety Stock Inv Costs = $z*\sigma_X*r*v$

where z = norminv of (1-company's cycle service level)

v = average value of goods / kg

r = company's holding cost rate

$\sigma_X = \sqrt{(E[L]*\sigma_D^2+E[D]^2 * \sigma_L^2)}$

where $E[L]$ = expected lead time of supply

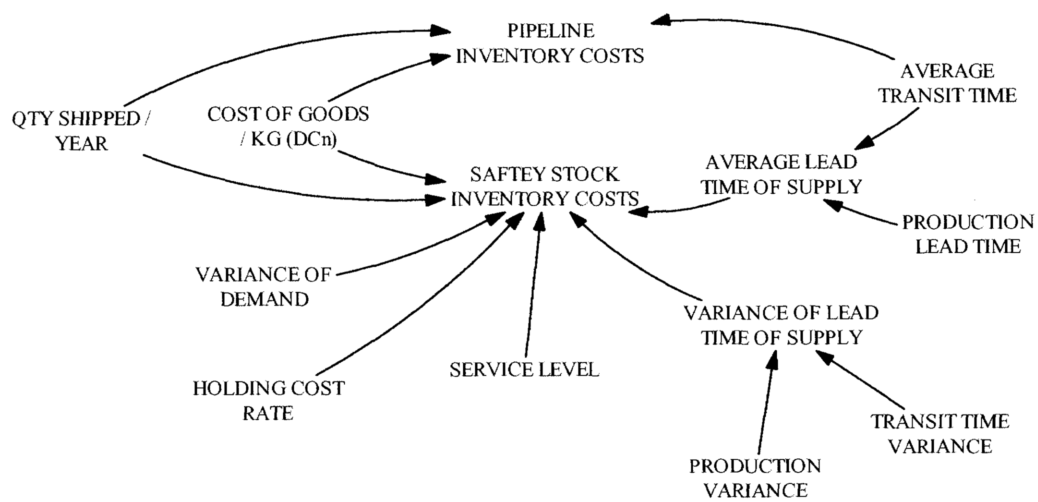
σ_D^2 = variance of demand / day

$E[D]$ = expected demand / day

σ_L^2 = variance of lead time of supply

In the model, standard deviation of demand is estimated at 20% of demand. Service Level is estimated at 95%. Holding cost rate is estimated at 18%. Production lead time is assumed to be constant at 60 days with zero variance. The expected lead time of supply is equal to 60 days plus the average transit time. The variance of lead time of supply is equal to variance of transit time (variance of production lead time is assumed to be zero). The average value of goods for each DC is estimated at $25 / kg. A summary of the pipeline and safety stock holding cost drivers are listed in Exhibit 4.12 below.

Exhibit 4.12: Pipeline and Safety Stock Inventory Drivers



5. Industry Case Results

The results are divided into three sections:

1) Transit Cost
2) Transit Cost + Inventory Cost
3) Transit Cost, Transit Time, and Transit Time Variance

In the first section, we ignore transit time, transit time variance, and inventory cost to focus solely on transit cost. This first section explores returns to scale and reduction of fixed costs. As a reminder, transit cost refers to all fixed and variable cost (exclusive of inventory holding cost) that the company incurs from the end of production until goods arrive at the DC.

In the second section, we assume that the drivers of inventory cost are known and correct. By adding inventory cost to transit cost, we arrive at a total network cost to evaluate across the 4 consolidation cases: Direct Shipment, Origin Port Consolidation, Destination Port Consolidation, and Origin Port and Destination Port Consolidation.

In the third section, we assume that the drivers of inventory cost are unknown or incorrect and we remove inventory cost from the equation. In this third section, we compare (a) the tradeoff between transit cost and average transit time and (b) the tradeoff between transit time and transit time variance. As a reminder, transit time refers to the time from end of production until goods arrive at the DC.

All results discussed in this section are based on the consolidation settings listed below in Exhibit 5.1.

Exhibit 5.1: Consolidation Rules for Results Discussion

CASE ABBREVIATION	FACT	ORIGIN	DEST	FULL
Origin Port Consolidation?	NO	YES	NO	YES
Destination Port Consolidation?	NO	NO	YES	YES
Factory Cutoff Value	16000kgs	16000kgs	16000kgs	16000kgs
Factory Max Wait Time	DV1	DV1	1 day	1 day
Origin Port Cutoff Value	16000kgs	16000kgs	16000kgs	16000kgs
Origin Port Max Wait Time	DV2	DV2	DV1	DV1
Destination Port Cutoff Value	16000kgs	16000kgs	16000kgs	16000kgs
Destination Port Max Wait Time	1 day	1 day	DV2	DV2

As noted in the exhibit above, the cutoff value will be set at 16000kgs for all transportation modes, while the max wait time will serve as the key decision variables (DV) for each consolidation case. Please note that the factory max wait time is set at 1-day for the destination port and full consolidation cases. Please note that the destination port max wait time is set to 1-day for the factory and origin port destination cases.

In this discussion, we will use (DV1,DV2) notation to indicate decision variable settings. Decision variable 1 (DV1) and decision variable 2 (DV2) for each case are listed above in Exhibit 5.1. For instance, factory consolidation decision variable settings of (14,8) indicates a max wait time at the factory (DV1) of 14 days and a max wait time at the origin port (DV2) of 8 days.

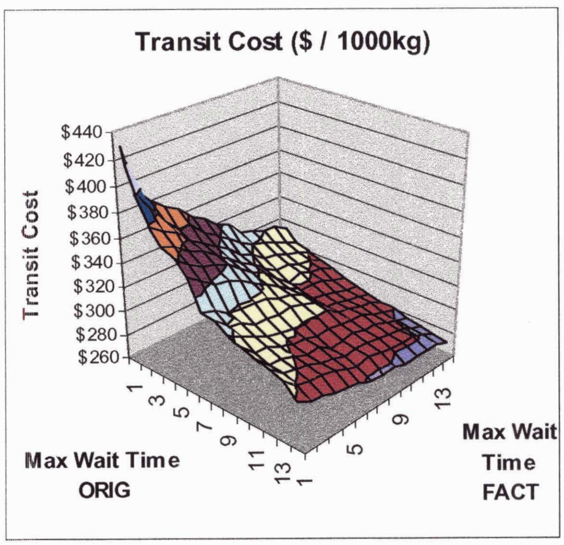
Throughout the results we use immediate ship policy as the base case. Under immediate ship policy, once goods finish production they are shipped immediately and do not consolidate at the origin port or destination port. Under this policy: factory, origin port, and destination port max wait times are all equal 1.

5.1 Transit Cost

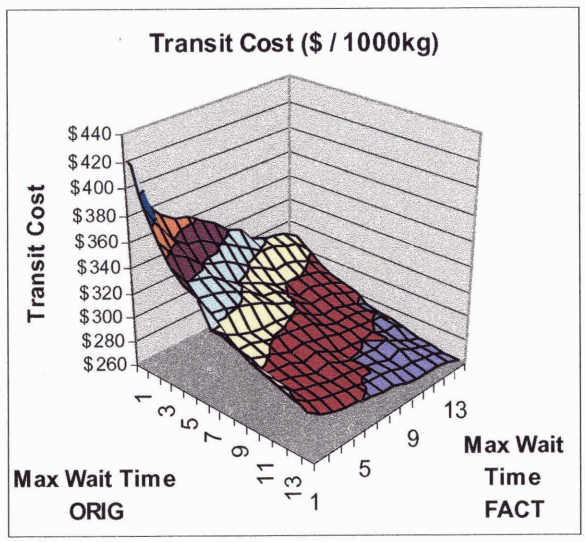
Exhibit 5.2 below displays the transit cost function for each of the four consolidation cases. Each color segment represents a $20 cost range. As noted in the introduction, freight logistics exhibit returns to scale. A combination of returns to scale and reduction of fixed costs can be clearly seen in the steep downward slopes of the cost functions in the each of the cases below. From these graphs, we can infer that longer max wait times result in larger shipment sizes and reduced per unit transportation costs.

Exhibit 5.2: Transit Cost Graphs

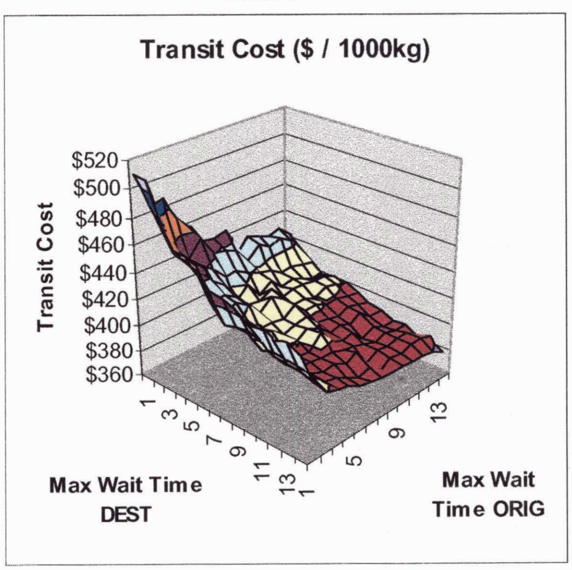
FACT



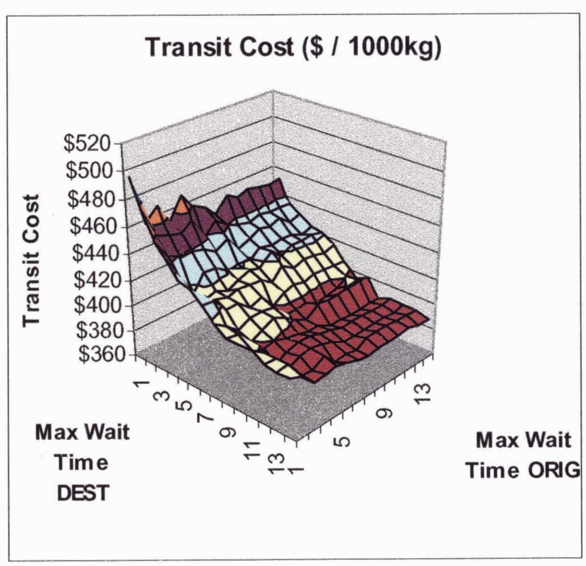
ORIG



DEST



FULL



Diminishing marginal returns from consolidation are also evident in Exhibit 5.2. As max wait times increase, the slope of the cost function decreases or flattens in each consolidation case. As max wait times increase, more and more shipments ship because they have reached the cutoff value rather than the max wait time. Opportunity for increased savings from consolidation becomes saturated the longer you wait, as more and more freight reaches its consolidation potential: a full truck or a full container.

Interestingly, under full consolidation (where port to port shipments are made primarily over one lane) the max wait time at the origin port is almost inconsequential. Under full consolidation the port to port lane is so heavy that ocean containers fill up daily. The opportunity for increased savings from origin port temporal consolidation is saturated from day 1.

Exhibit 5.2 also shows that transit cost for destination port and full consolidation is higher across the board when compared to factory and origin port consolidation. Exhibit 5.3 below reinforces this finding. For each set of decision variables (DV) below, transit cost for destination port and full consolidation is almost $100 greater than transit cost for factory or origin port consolidation.

Exhibit 5.3: Transit Cost Summary

Transit Cost ($)

DV	FACT	ORIG	DEST	FULL
(1,1)	432	421	512	498
(1,7)	330	322	452	428
(1,14)	299	297	436	405
(7,1)	351	350	445	453
(7,7)	311	301	405	399
(7,14)	278	277	387	388
(14,1)	312	310	421	451
(14,7)	286	276	395	405
(14,14)	270	261	375	387

The main reasons for this difference are:

a) The majority of goods in the case at hand are exported from either Shanghai or Ningbo. These two ports are within one hour of each other. Thus, consolidating Shanghai and Ningbo allows for increased risk pooling, but does not requires significant cost.

b) The majority of goods in the case at hand are imported are through Chicago or Atlanta. Consolidating shipments in LA requires a shift from short-haul inland truck to long-haul inland truck. Consolidating at the destination port in LA is more expensive due to long-haul trucking costs.

Thus far, it appears that factory and origin port consolidation cases are superior to destination port and full consolidation cases. Exhibit 5.4 below gives decision variable settings that result in the minimum transit cost for each case. It should be clearly noted that the minimum cost temporal consolidation setting for all cases is the maximum "maximum wait time" allowed in the model, 14 days.

Exhibit 5.4: Transit Cost Savings Summary

	FACT	ORIG	DEST	FULL
Base Case	432	432	432	432
Minimum	270	261	375	387
% Savings	37%	39%	13%	10%
DV	(14, 14)	(14, 14)	(14,14)	(14,14)

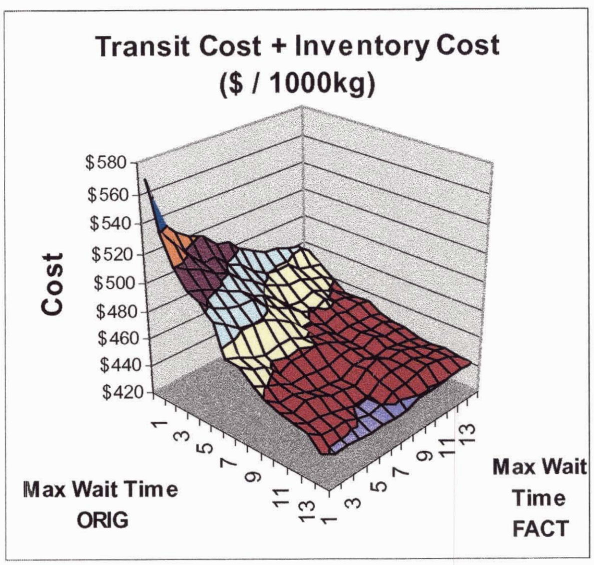
Compared to the base case, we find potential for transit cost savings of 37% in factory consolidation; 39% in origin port consolidation; 13% in destination port consolidation; and 10% in full consolidation.

5.2 Total Transit Cost and Inventory Cost

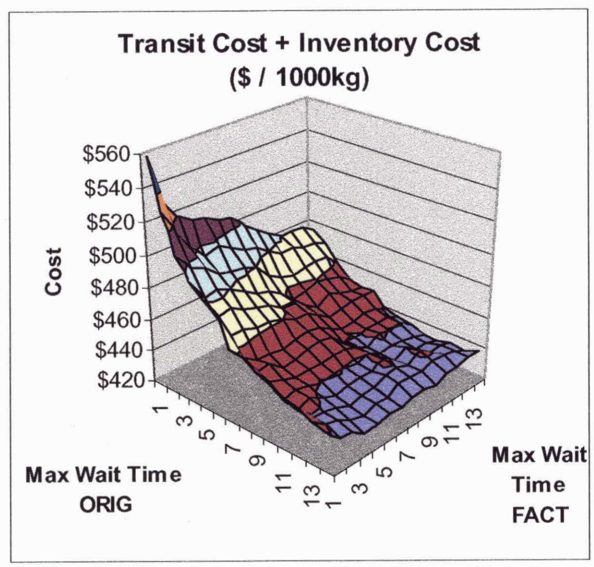
After including inventory costs, we find that the slopes in Exhibit 5.5 are similar to those in Exhibit 5.2. This finding indicates that inventory cost plays a minor role in the industry case. In general, as wait times increase, transit cost should decrease and inventory cost should increase. Due to the nature of the product, however, inventory cost increases are not significant when weighed against transit cost savings. The case would likely be different if the industry involved fashion or high tech items that have higher value to weight ratios.

Exhibit 5.5: Transit Cost + Inventory Cost Graphs

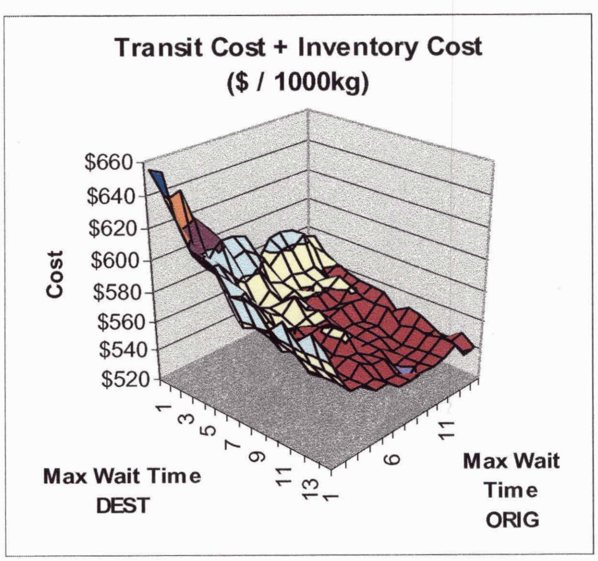
FACT



ORIG



DEST



FULL

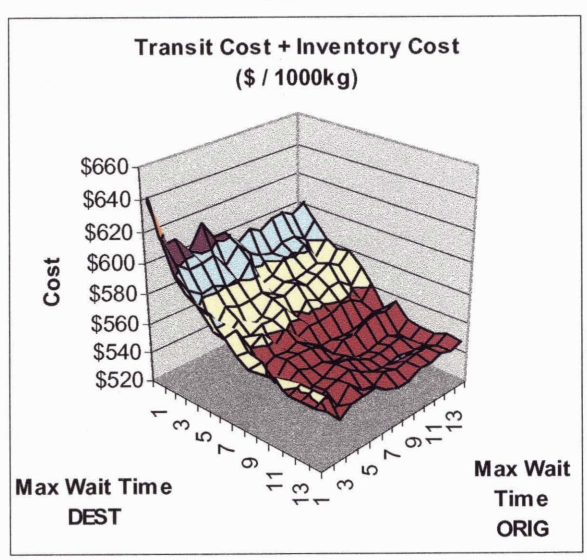


Exhibit 5.6 below reinforces the finding in section 5.1, that transit costs for destination port and full consolidation are higher across the board when compared to factory and origin port consolidation. We again find that total transit and inventory cost for destination port and full consolidation are approximately $100 greater than for factory or origin port consolidation.

Exhibit 5.6: Transit Cost + Inventory Cost Summary

DV	FACT	ORIG	DEST	FULL
(1,1)	572	563	657	643
(1,7)	473	466	600	575
(1,14)	443	444	592	559
(7,1)	507	505	597	602
(7,7)	461	452	562	551
(7,14)	434	431	543	543
(14,1)	475	475	574	601
(14,7)	448	439	553	562
(14,14)	440	436	540	547

Transit cost and inventory cost represent the model's relevant costs. Assuming that inventory cost inputs are correct, a decision can be made by selecting the minimum cost policy of the four consolidation cases. Based on the minimum total inventory and transit cost found in exhibit 5.7 below, the recommended consolidation policy is origin port consolidation, factory max wait time = 4 days, origin port max wait time = 14 days.

Exhibit 5.7: Transit Cost + Inventory Cost Savings Summary

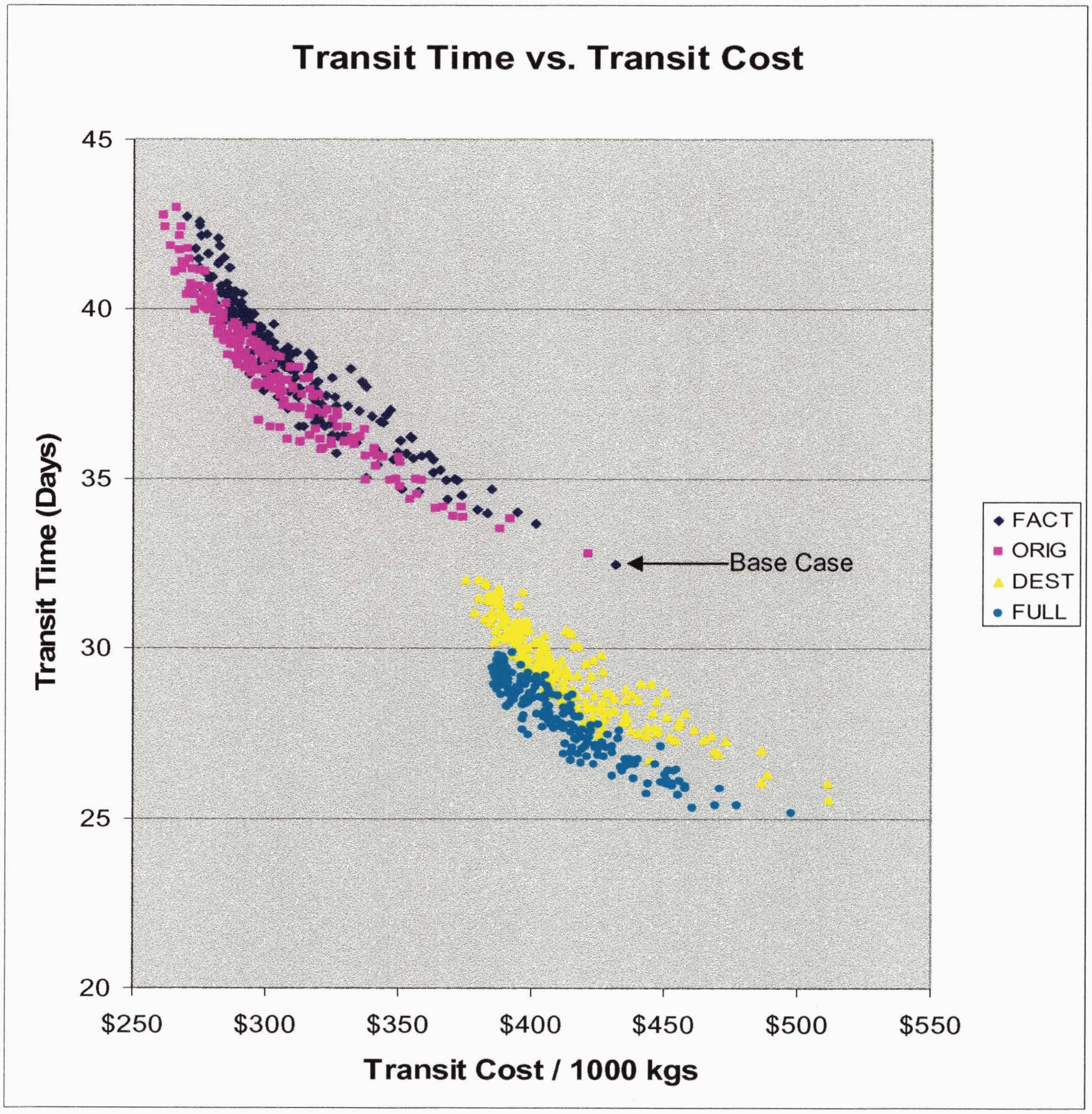
	FACT	ORIG	DEST	FULL
Base Case	572	572	572	572
Minimum	434	429	534	538
% Savings	24%	25%	7%	6%
DV	(7, 14)	(4, 14)	(14, 5)	(9,13)

After including inventory costs, the potential for cost savings becomes more realistic, decreasing from 37% to 24% in case FACT; 38% to 24% in case ORIG; 18% to 13% in case DEST; and 10% to 8% in case FULL. Consolidation settings that minimize transit costs are not the same settings that minimize total transit and inventory costs!

5.3 Transit Cost, Transit Time, and Transit Time Variance (Tradeoffs)

Removing inventory cost from the equation allows us to have a crisp look at the tradeoff between transit cost and average transit time. Exhibit 5.8 below shows a clear relationship between transit time and transit cost: the longer the transit time, the lower the per unit transit cost.

Exhibit 5.8: Transit Cost vs. Transit Time Graph



Longer max wait times result in longer average transit times. Likewise, longer wait times result in larger shipment sizes, which reduce the per unit transportation cost.

Exhibit 5.8 also shows that the tradeoff between transit time and transit cost continues across spatial consolidation cases. Factory and origin port consolidation offer slower transit times at lower costs, while destination port and full consolidation offer faster transit times at higher costs. Most strikingly, the four cases seem to form a continuum of options along the transit time / transit cost spectrum.

In this industry case, destination port and full consolidation function like different mode of transportations. Long-haul truck service from LA expedites goods that would still be on the water or rail, and results in dramatic improvements in transit time. As we saw in section 5.1, transit costs are higher across the board for destination port and full consolidation. Exhibit 5.8 shows that you get what you pay for.

If air shipment was included in this study its points would extend Exhibit 5.8 to the far right, where we would find a stream of points around the $3000 (per 1000 kg) 5 day transit time mark. Adding sea-air, bulk air freight, and express courier transportation modes to the model would provide a nearly continuous spectrum of transit cost / transit time options.

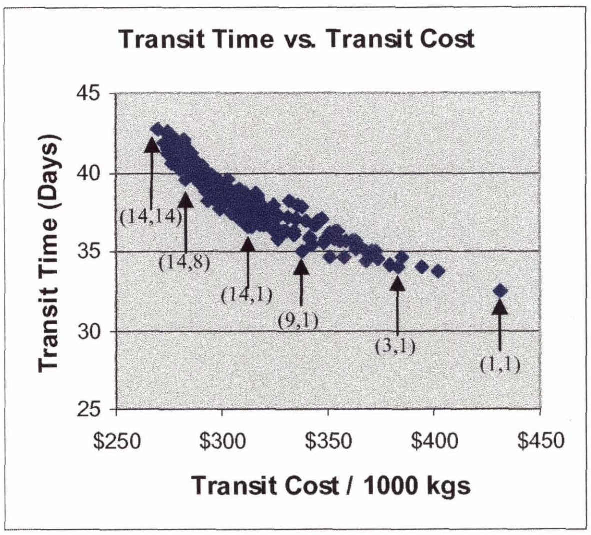
A key result of this model is that consolidation allows a company to fine tune the transit cost / transit time spectrum to its liking. But the question for the company remains: What are its priorities? How is does it value the tradeoff between cost and time? How does it pick from among the myriad of points along the tradeoff continuum?

To attempt to answer this question, let's start by selecting the best transit time vs. transit cost options for each of the four consolidation cases. Best options are settings that have the lowest transit time for a given cost; they are the points make up the bottom of the transit cost / transit time curve. Second, let's examine transit time variance for each of the settings to determine if the best options in the transit cost / transit time tradeoff are also the best options in the transit cost / transit time variance tradeoff.

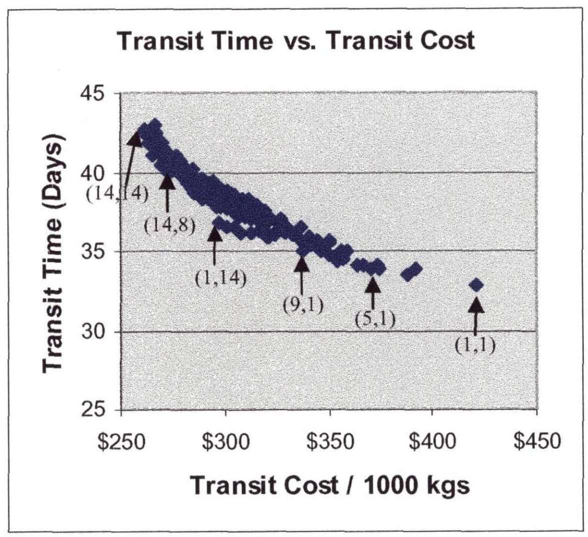
Exhibit 5.9 below lists five or six best options for each consolidation case. We will map these same settings against the Transit Cost / Transit Time Variance tradeoff in the next exhibit.

Exhibit 5.9: Transit Cost vs. Transit Time (Best Options Graph)

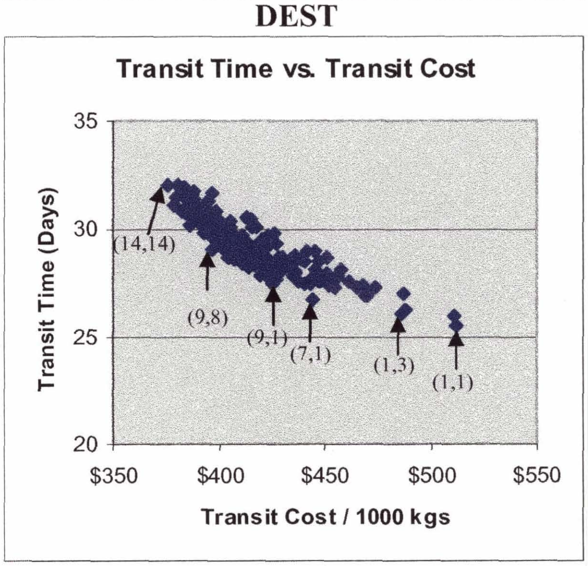
FACT



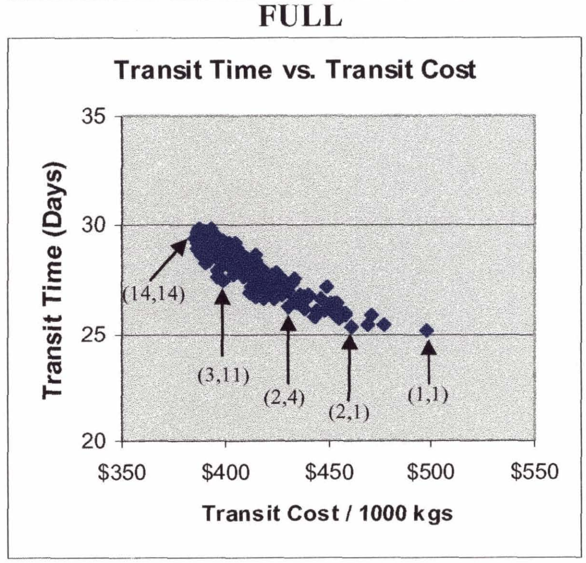
ORIG



DEST



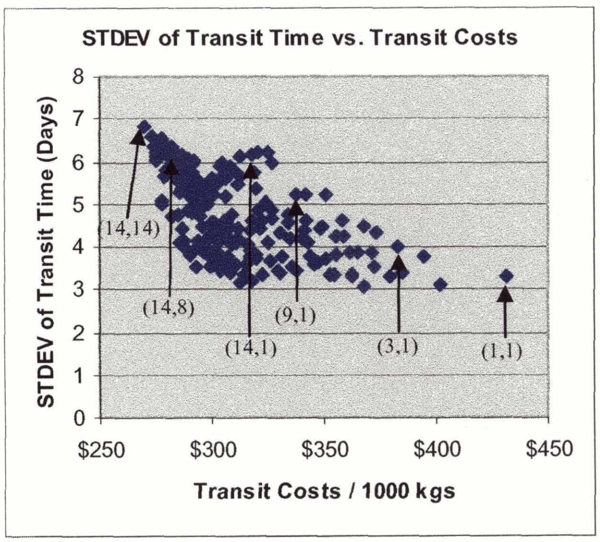
FULL



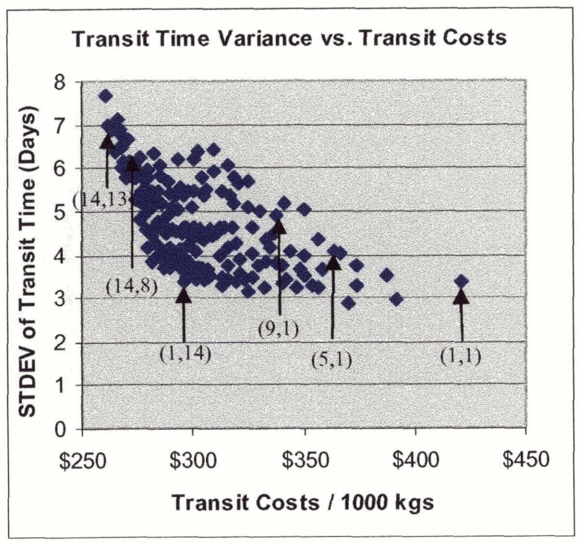
In Exhibit 5.10 below we find that the settings selected as best options for the transit cost / transit time tradeoff do not correspond as best options in the transit variance / transit time tradeoff. In fact, in many cases the best option for the transit cost / transit time tradeoff is nearly the worst option for the transit variance / transit time tradeoff. Considering that inventory costs increase as transit time increases and also as transit time variance increases, we are left to balance a third tradeoff: the transit time / transit variance tradeoff.

Exhibit 5.10: Transit Cost vs. Transit Time Variance (Best Options Graph)

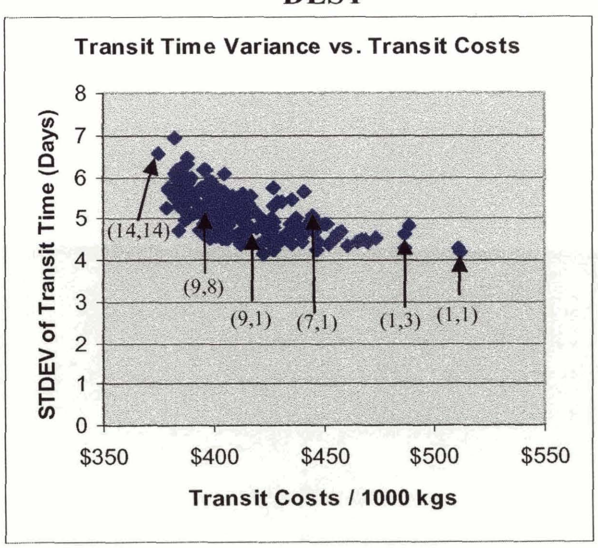
FACT



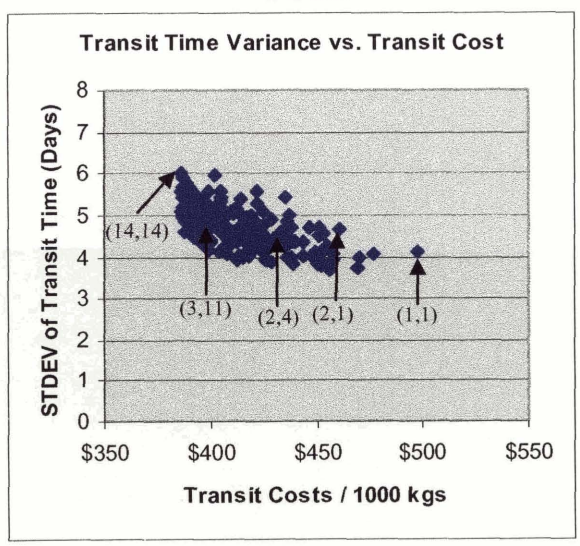
ORIG



DEST



FULL



So where does this leave us? First, we know that the tradeoff between transit cost and transit time is alive and well in the world of logistics. Consolidation only allows you to fine tune the frequency of the transit cost vs. transit time spectrum. Without a strong understanding of the value of transit time and transit time variance, consolidation is likely irrelevant. At the same time, if the drivers of inventory cost are known consolidation can result in significant savings from the base case: 24% savings in the case at hand!

6. Summary of Results

- Simulation modeling provides a clear picture of the implications of different consolidation rules.
- As the time allowed for consolidation increases, transit times increase and per unit freight rates decrease.
- The tradeoff between time and cost is seen among and across consolidation cases.
- If the drivers of pipeline and safety stock inventory costs are known, simulation modeling can be used to determine the best consolidation rules.
- In the case at hand, we find 24% savings when comparing the best rules to the base case, an immediate ship policy.
- If the drivers of pipeline and safety stock inventory costs are unknown, or if the products being shipped are diverse in cost and importance, simulation modeling can still provide a clear picture of the tradeoff between transit time and transit cost.
- In the case at hand, we find that destination port consolidation functions like a different mode of transportation. As long-haul truck service from LA expedites goods that would still be on the water or rail, and results in dramatic improvements in transit time as well as dramatic increases in transit cost.
- The best option for a given transit time vs. transit cost tradeoff is usually not the best option for the transit variance vs. transit cost tradeoff.
- Without a strong understanding of the value of transit time and transit time variance, consolidation is difficult to implement effectively.

7. Future Research

Future research interests in this area are threefold.

- To introduce logic into the model that restricts shipments to complete orders only. The current logic allows for split orders and thus overestimates the advantages to larger cutoff values.

- To analyze the effect of ordering policies on consolidation. It is my hypothesis that more frequent orders to the factory will reduce cycle stock inventory costs and decrease the variance in lead time for consolidation. Lean production with consolidation will allow you to achieve economies of scale in transportation, while at the same time reducing the cycle stock.

- To add product classification logic to the model. The current logic assumes that each DC holds products that similar in their value / weight ratio. By adding product classification to the model, we could achieve better insights as to how consolidation rules should vary depending on product classification.

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Appendix

Exhibit A.1: Reference Table 1, Factory to DC (100 rows)

LANE ID	FACTORY	ORIGIN PORT	DESTINATION PORT	DC	FACTORY CUTOFF VALUE (KGS)	FACTORY MAX WAIT TIME	ESTIMATED ANNUAL WEIGHT (KGS)	ESTIMATED # OF ANNUAL ORDERS	AVERAGE WEIGHT / ORDER (KGS)	WEIGHT PER ORDER (STDEV)
L01	F04	OP1	DP4	DC1	16000	1	228	5	46	9
L02	F12	OP4	DP4	DC1	16000	1	4090	15	273	55
L03	F18	OP4	DP4	DC2	16000	1	4000	5	800	160
L04	F03	OP4	DP4	DC3	16000	1	363	5	73	15
L05	F18	OP4	DP4	DC3	16000	1	1370	5	274	55
L06	F20	OP4	DP4	DC3	16000	1	4000	5	800	160
L07	F36	OP1	DP4	DC3	16000	1	2729	30	91	18
L08	F41	OP4	DP4	DC3	16000	1	1124	65	17	3
L09	F08	OP4	DP4	DC4	16000	1	13697	8	1712	342
L10	F13	OP1	DP4	DC4	16000	1	175	1	175	35
L11	F24	OP4	DP4	DC4	16000	1	1111	1	1111	222
L12	F25	OP4	DP4	DC4	16000	1	411	2	206	41
L13	F26	OP4	DP4	DC4	16000	1	1739	1	1739	348
L14	F27	OP1	DP4	DC4	16000	1	1521	2	761	152
L15	F28	OP4	DP4	DC4	16000	1	648086	90	7201	1440
L16	F35	OP1	DP4	DC4	16000	1	43880	4	10970	2194
L17	F37	OP4	DP4	DC4	16000	1	209423	90	2327	465
L18	F40	OP4	DP4	DC4	16000	1	4606	1	4606	921
L19	F42	OP4	DP4	DC4	16000	1	361	1	361	72
L20	F02	OP4	DP4	DC5	16000	1	18583	2	9291	1858
L21	F06	OP4	DP4	DC5	16000	1	416305	29	14355	2871
L22	F07	OP4	DP4	DC5	16000	1	1045522	70	14936	2987
L23	F09	OP4	DP4	DC5	16000	1	2472	2	1236	247
L24	F11	OP4	DP4	DC5	16000	1	33570	1	33570	6714
L25	F14	OP4	DP4	DC5	16000	1	69	1	69	14
L26	F15	OP4	DP4	DC5	16000	1	30750	2	15375	3075

Exhibit A.2: Reference Table 2, Factory to Origin Port (100 Rows)

Factory Name	Product Type	Origin Port Consolidation?	Factory ID	Origin Port	Factory To Origin Port	Truck Costs	Primary Port ID	Primary Port	Truck Costs to Primary Port	Consolidation Port ID	Consolidation Port	Truck Costs to Consolidation Port
xxx…	2	1	F01	OP4	F01OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	2	1	F02	OP4	F02OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	1	1	F03	OP4	F03OP4	100	OP4	*SHA*	100	OP4	SHA	100
xxx…	1	1	F04	OP1	F04OP1	100	OP1	*DLC*	100	OP1	DLC	100
xxx…	2	1	F05	OP4	F05OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	2	1	F06	OP4	F06OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	2	1	F07	OP4	F07OP4	150	OP3	NGB	100	OP4	SHA	150
xxx…	2	1	F08	OP4	F08OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	2	1	F09	OP4	F09OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	1	1	F10	OP4	F10OP4	100	OP4	*SHA*	100	OP4	SHA	100
xxx…	2	1	F11	OP4	F11OP4	100	OP4	SHA	100	OP4	SHA	100
xxx…	1	1	F12	OP4	F12OP4	150	OP5	*SZX*	100	OP4	SHA	150
xxx…	2	1	F13	OP1	F13OP1	100	OP1	DLC	100	OP1	DLC	100
xxx…	2	1	F14	OP4	F14OP4	100	OP4	SHA	100	OP4	SHA	100

Exhibit A.3: Reference Table 3, Origin Port to Destination Port (9x9, 81 rows)

PORT TO PORT					COSTS		FCL TRANSIT DISTRIBUTION			LCL TRANSIT DISTRIBUTION			DAYS AVAILABLE							Decision Variables	
OP	DP	ORIGIN PORT	DEST PORT	PORT TO PORT	LCL RATE / 1000 KGS	FCL RATE	MIN	MEAN	STDEV	MIN	MEAN	STDEV	1	2	3	4	5	6	7	Origin Port Cutoff Value	Origin Port Max Wait Time
DLC	ATL	OP1	DP1	OP1DP1	200	3,000	21	28	2	21	28	2	1	0	0	0	1	0	0	16000	1
DLC	CHI	OP1	DP2	OP1DP2	190	2,800	15	25	2	15	25	2	1	0	0	0	1	1	1	16000	1
DLC	HOU	OP1	DP3	OP1DP3	180	2,700	17	26	2	17	26	2	1	0	0	0	1	0	1	16000	1
DLC	LAX	OP1	DP4	OP1DP4	150	2,200	12	15	2	12	14	2	1	0	1	0	1	1	1	16000	1
DLC	NYC	OP1	DP5	OP1DP5	200	3,000	23	29	2	23	29	2	1	0	0	0	1	0	1	16000	1
DLC	X	OP1	DP6	OP1DP6	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	16000	1
DLC	X	OP1	DP7	OP1DP7	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	16000	1
DLC	X	OP1	DP8	OP1DP8	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	16000	1
DLC	X	OP1	DP9	OP1DP9	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	16000	1
HGH	ATL	OP2	DP1	OP2DP1	200	3,000	21	28	2	21	28	2	1	0	0	0	1	0	0	16000	1
HGH	CHI	OP2	DP2	OP2DP2	190	2,800	15	25	2	15	25	2	1	0	0	0	1	0	1	16000	1
HGH	HOU	OP2	DP3	OP2DP3	180	2,700	17	26	2	17	26	2	1	0	0	1	0	1	1	16000	1
HGH	LAX	OP2	DP4	OP2DP4	150	2,200	12	15	2	12	14	2	1	1	0	1	0	1	1	16000	1
HGH	NYC	OP2	DP5	OP2DP5	200	3,000	23	29	2	23	29	2	1	0	0	0	0	0	1	16000	1

Exhibit A.4: Reference Table 4, Destination Port to DC (9 rows)

DC - DP LINK							DESTINATION TRUCK COSTS			FTL TRANSIT			LTL TRANSIT		
DC NAME	DC ID	DP	DP ID	Primary Port	Consolidation Port	DP -- DC Lane	LTL / 1000 KG (<5000 KGS)	LTL / 1000 KG (>5000 KGS)	FTL	MIN	MEAN	STDEV	MIN	MEAN	STDEV
xxx…	DC1	LAX	DP4	LAX	LAX	DP4DC1	29	23	232	1	1	1	2	2	2
xxx…	DC2	LAX	DP4	ATL	LAX	DP4DC2	285	81	2,279	1	2	1	2	3	2
xxx…	DC3	LAX	DP4	ATL	LAX	DP4DC3	351	45	2,809	1	1	1	2	2	2
xxx…	DC4	LAX	DP4	ATL	LAX	DP4DC4	385	74	3,078	1	1	1	2	2	2
xxx…	DC5	LAX	DP4	CHI	LAX	DP4DC5	334	50	2,669	1	1	1	2	2	2
xxx…	DC6	LAX	DP4	HOU	LAX	DP4DC6	260	27	2,082	1	1	1	2	2	2
xxx…	DC7	LAX	DP4	HOU	LAX	DP4DC7	260	27	2,080	1	1	1	2	2	2
xxx…	DC8	LAX	DP4	HOU	LAX	DP4DC8	260	27	2,080	1	1	1	2	2	2
xxx…	DC9	LAX	DP4	NYC	LAX	DP4DC9	411	43	3,290	1	1	1	2	2	2

Reference Table 4 Continued…

DECISION VARIABLES			PRIMARY PORT				FTL			LTL		
Destination Port Consolidation?	TRUCK CUTOFF WEIGHT	TRUCK MAX WAIT	ROAD MILES	LTL / 1000 KG (<5000 KGS)	LTL / 1000 KG (>5000 KGS)	FTL	MIN	MEAN	STDEV	MIN	MEAN	STDEV
1	16000	1	20	29	23	232	1	1	1	2	2	2
1	16000	1	542	101	81	806	1	2	1	2	3	2
1	16000	1	221	57	45	453	1	1	1	2	2	2
1	16000	1	480	92	74	738	1	1	1	2	2	2
1	16000	1	260	62	50	496	1	1	1	2	2	2
1	16000	1	50	33	27	265	1	1	1	2	2	2
1	16000	1	50	33	27	265	1	1	1	2	2	2
1	16000	1	50	33	27	265	1	1	1	2	2	2
1	16000	1	200	54	43	430	1	1	1	2	2	2

Reference Table 4 Continued…

CONSOLIDATION PORT				FTL			LTL		
ROAD MILES	LTL / 1000 KG (<5000 KGS)	LTL / 1000 KG (>5000 KGS)	FTL	MIN	MEAN	STDEV	MIN	MEAN	STDEV
20	$ 29	$ 23	$ 232	1	2	1	2	3	3
1881	$ 285	$ 228	$2,279	1	3	2	2	5	3
2363	$ 351	$ 281	$2,809	1	3	2	2	5	3
2607	$ 385	$ 308	$3,078	1	3	2	2	5	3
2235	$ 334	$ 267	$2,669	1	3	2	2	5	3
1702	$ 260	$ 208	$2,082	1	3	2	2	5	3
1700	$ 260	$ 208	$2,080	1	3	2	2	5	3
1700	$ 260	$ 208	$2,080	1	3	2	2	5	3
2800	$ 411	$ 329	$3,290	1	3	2	2	5	3

Exhibit A.5: Reference Table 5, Destination Port (9 rows)

DEST PORT		BROKERAGE	FCL TIME TO AVAILABILITY			LCL TIME TO AVAILABILITY		
DP ID	DEST PORT	FIXED FEE	MIN	MEAN	STDEV	MIN	MEAN	STDEV
DP1	ATL	$ 200	1	3	1	2	4	3
DP2	CHI	$ 200	1	3	1	2	4	3
DP3	HOU	$ 200	1	3	1	2	4	3
DP4	LAX	$ 200	1	3	4	2	4	5
DP5	NYC	$ 200	1	3	2	2	4	3
DP6	X	$ 200	1	3	2	2	4	3
DP7	X	$ 200	1	3	2	2	4	3
DP8	X	$ 200	1	3	2	2	4	3
DP9	X	$ 200	1	3	2	2	4	3

Exhibit A.6: Reference Table 6, DC (9 rows)

DC	DC ID	FIXED COST / RECEIPT	E(D) (/day)	$E(D)^2$ (/day)	E(Production Leadtime)	E(Transit Leadtime)	E(Total Leadtime)	σ^2_D	σ^2_L	r
xxx...	DC1	100	12	140	60	24	84	6	3.98	0.18
xxx...	DC2	100	11	120	60	24	84	5	3.98	0.18
xxx...	DC3	100	26	690	60	24	84	28	3.98	0.18
xxx...	DC4	100	2,534	6,422,530	60	24	84	256901	3.98	0.18
xxx...	DC5	100	5,005	25,049,525	60	24	84	1001981	3.98	0.18
xxx...	DC6	100	5	24	60	24	84	1	3.98	0.18
xxx...	DC7	100	26	652	60	24	84	26	3.98	0.18
xxx...	DC8	100	56	3,123	60	24	84	125	3.98	0.18
xxx...	DC9	100	263	69,306	60	24	84	2772	3.98	0.18

Reference Table 6 Continued....

$ / kg	Cycle Service Level	k	new (σ)	SS	SS Holding Costs	Annual Demand	Pipeline Holding Costs
25	0.95	1.645	133	219	$ 984	4317	$ 53
25	0.95	1.645	30	49	$ 220	4000	$ 49
25	0.95	1.645	71	117	$ 527	9586	$ 118
25	0.95	1.645	6865	11292	$ 50,815	925009	$ 11,404
25	0.95	1.645	13558	22301	$ 100,354	1826807	$ 22,522
25	0.95	1.645	13	22	$ 98	1783	$ 22
25	0.95	1.645	69	114	$ 512	9321	$ 115
25	0.95	1.645	151	249	$ 1,121	20398	$ 251
25	0.95	1.645	713	1173	$ 5,279	96090	$ 1,185