AN OPTIMIZATION-SIMULATION APPROACH FOR LOCATING WAREHOUSES IN LOGISTICS NETWORKS

by

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ABSTRACT OF THE THESIS

AN OPTIMIZATION-SIMULATION APPROACH

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Thesis Director:

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This thesis introduces a hybrid optimization-simulation model to locate international and regional warehouses for importer companies. The model assumes multiple products, one or two ports of entry, several geographic regions for the continental US, two international warehouses (IWH) and six regional warehouses (RWH). Demand and transit times are assumed probabilistic and several inventory control mechanisms are assumed. Certain cost based constraints for warehouse locations are included in the model. We conducted many experiments and our observation has been that the warehousing location assignments follow a branching pattern starting from the port of entry and stretching towards downstream echelons. The segments of these branches, meaning distance between Port-IWH or IWH-RWH pairs, get longer or shorter depending on the transportation cost inputs of the model. Basically, in order to minimize the overall

transportation costs, the optimization model searches for a solution to balance the cost ratio between these segments. According to our model, warehousing cost and demand distribution appear to be important factors for selecting warehouse locations in the logistics network. If there are multiple potential neighboring regions, the optimization model normally chooses the low-cost region. However, when these regions are similar to each other according to the warehousing cost, the model seeks for a location which is closer to the high-demand regions.

Preface

A generic simulation tool has been developed in order to study the logistics network of importer companies. Multiple scenarios were experimented based on different combinations of port of entries, transportation modes, import volume distributions and warehousing costs.

This thesis is organized as follows. Chapter 1 makes a brief introduction to the logistics networks, represents the objective of this thesis and then reviews the past literature about facility location problems. Chapter 2 provides detailed information about logistics networks of importer companies, such as, ports, warehouses, customers and modes of transportation. After that, Chapter 2 continues with the factors that affect the site selection problem of warehouses. Chapter 3 talks about the problem approach followed by this thesis and then discusses the proposed model in two sections as: 1) simulation model, and 2) optimization model. Chapter 4 talks about the general scenario designed for this thesis and then introduces the proposed model inputs. This is followed by the representation of experimentation methodology together with the discussion of results in Chapter 5. Chapter 6 summarizes this thesis and represents conclusions together with improvements for future work. Appendix A, B and C represent the inputs used in developing the experiments and provide detailed information about these inputs. Appendix D provides information about the simulation template. Finally, Appendix E represents a sample output data for both simulation and optimization models.

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Chapter 1

Introduction and Literature Review

The Council of Supply Chain Management Professionals (2006) defines logistics as "the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information, from the point of origin to the point of consumption for the purpose of conforming to customer requirements". This includes inbound, outbound, internal, and external movements. The overall worldwide logistics-related expenses were $3.4 trillion for 1996 (Gourdin, 2006) – with the North American share of 27%, European Union share of almost 28% and Asia/Pacific Nations share of about 19%. Generally speaking, the cost elements in a logistics network can be classified into three groups: transportation, inventory and administration costs. Transportation and inventory costs are usually about 80-90% of the total logistics cost, both are related to location of facilities. By properly selecting facility locations, companies try to reduce costs of their logistics.

The objective of this thesis is to develop a tool to help companies in making their warehouse location decisions and understand certain factors that has crucial effect on this location problem. In particular, we developed an optimization-simulation approach for optimal location of warehouses to a predetermined set of alternative locations. We focus our attention to industries that are mainly in the import business. Here, we take into consideration the material flow from the point of importation up to delivery to customers.

1.1 Literature Review

According to Gourdin (2006), "most comprehensive facility location techniques fall into one of the following categories: optimizations, simulations or heuristics". Below we will summarize the early work in these areas.

An early work on optimizing warehouse locations can be found in Baumol and Wolfe (1957). In this paper, location problem was handled as a standard transportation problem with an objective of minimizing total delivery cost. Their model had the following major features: (1) Cost variables could be nonlinear functions. (2) Capacity constraints were included in the model. Despite the fact that they were talking about the presence of warehouse capacity constraints, their solutions ignored these restrictions. (3) Shipment quantities from factories (suppliers) were related to the warehouses on their way to the retailers. Baumol and Wolfe claimed that, generally speaking, there were no useful computational procedures to calculate the definite least possible amount of a concave cost function.

Khumawala (1972) introduced mixed integer programming formulation of the warehouse location problems with an efficient branch and bound algorithm. According to Khumawala, Effroymson and Ray (1966) had earlier applied branch and bound technique to calculate optimal solutions for warehouse location problems. But, his technique is drastically more efficient, as he put it. The first improvement was setting a branching decision rule at every level in order to select an available warehouse location from the overall set of available locations. The second improvement was about managing the integer variables. Initially, by using this technique the algorithm was solved as if it was a linear program.

Mixed integer programming was revisited by Melachrinoudis and Min (2007). This time the objective was to redesign a warehouse network in order to minimize total supply-chain cost including production, transportation, warehousing and relocating costs, and at the same time to maximize the closure and/or consolidation of the unnecessary warehouses. In other words, the program was constructed in order to optimize a given warehouse network by simultaneously eliminating redundant (existing) warehouses and locating new potential warehouse. Their mathematical formulation took into account certain restrictions such as: production capacity of the plants, supplying of all customer demand and serving every customer in a given time frame.

Related work about simulation techniques for warehousing networks can be found in Williams and Gunal (2003). This study presented a general summary about a commercial logistics simulation software package, called SimFlex™. As a matter of fact, this software tool was claimed to be capable of dealing with location, manufacturing, transportation, procurement, distribution, sales and tradeoff problems. In the given case study, manufacturing facility and distribution center locations were specified to the model with inventory control policies and customer demand data. Furthermore, product types and their hierarchical constituent particles were fed along with logistic services and delivery policies. Some other variables were also allowed in the model, such as, processing times and shipment costs.

Another way of approaching warehouse location problems is to combine optimization techniques with simulation modeling in order to utilize their specialties altogether. A related work about designing distribution networks was presented in Ko, et al (2006) with a hybrid optimization-simulation approach considering the warehouses' performance. A genetic algorithm was used in the optimization model to locate storage space to various locations depending on their demands at different points in time. A simulation model was used to generate stochastic demand and time components.

In this thesis, we built on the model developed by Ko, et al (2006) by incorporating inventory control policies into facilities and thereby controlling the product flow in the logistics network. In the end, we came up with a simulation model which is capable of modeling most of the important aspects of this logistics network including ports, international warehouses, regional warehouses and customer market.

Chapter 2

Problem Definition

By definition, an importer can be a legal entity, form or an individual which brings merchandise from a source outside the country into a domestic market through commercial means. In this thesis, we focus on the logistics networks arising in the supply chains of importer companies (as shown in Figure 2.1). We assume that the logistics network spans from the supplier all the way to the delivery of the product to the customer. Nodes of such logistics network may consist of ports, warehouses and customers, and transportation modes in between. In this section, we describe the key components to provide a foundation for the idea of logistics network under the study in this thesis.

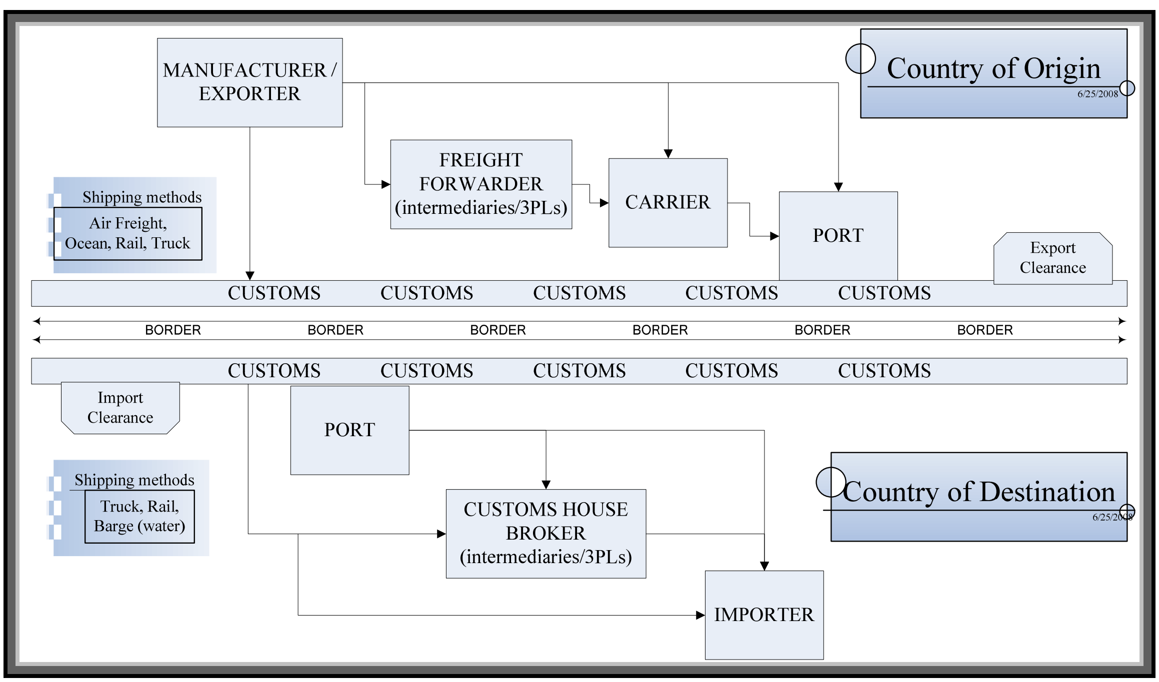

Figure 2.1: A typical supply chain for an importer company

2.1 Ports

Ports (seaports) are the facilities for receiving ships and transferring cargo. For our model, ports are the only point of entries for the imported merchandise. They constitute important nodes where cargo experiences delays in the logistics network. Ports receive shipments and store them until a convenient mode of transportation becomes available. The arrival time and the amount of shipments can be based on schedules, and moreover stochastic transit times may be added to the port logic. Furthermore, the cost issues associated with ports can be included into the system in terms of handling costs per shipment, port fees and taxes. These cost parameters can be used to calculate overall port expenses in the network.

2.2 Warehouses

Warehouses are commercial buildings for storage of goods. Two types of warehouses are considered in the logistics model: international and regional warehouses. The usual scenario is the transportation of goods from ports to international warehouses (IWH) and then from international warehouses to regional warehouses (RWH).

International warehouses are the main (primary) storage facilities for the importer company within the country of destination. All of the imported merchandise is being transported to associated international warehouses through the ports. In addition to the stock keeping property, these warehouses may also be responsible for various value added operations, consolidation and deconsolidation of the shipments. Nonetheless, their primary objective is to replenish inventory levels of the regional warehouses. Regional warehouses are considered to be much smaller in size compared to international warehouses. Their primary objectives are keeping local inventory and supplying the market demand in acceptable time frames.

Inventory control policies for these warehouses are based on periodic review with inventory positioning. Simply put, if the inventory position goes below the re-order level for each time the inventory is reviewed, an order is created for the required amount of the product. There is also the concept of safety stock which represents the buffer stock for compensating delays in supply-chains and variation in customer demand.

2.3 Customers

Customers constitute the demand for products in our logistic network. In this study, we represented customers by regions (i.e., clustered markets). According to Jain and Dubes (1988), the description of a cluster is “connected regions of a multi-dimensional space containing a relatively high density of points, separated from other such regions by a region containing a relatively low density of points”. Furthermore, clusters may be defined as the division of entities in groups based on some aspects of the entities’ characteristics (Anderberg, 1973). These definitions are used to determine the clusters in the network. Each cluster is representing a given region that has its own demand distribution which symbolizes the market enclosed by that region.

2.4 Modes of Transportation

Possible transportation means that can be used in between echelons are air freight, shipping, trucking and rail. For the sake of simplicity, we are going to implement some of these transportation methods into the model. Between product origin and port of entry, the transportation method was set to shipping. Trucking and rail are the two common methods for inland transportation. Therefore, transportation between ports and international warehouses is set to be made by rail and/or trucking services. Only trucking service was implemented into the model in between warehouses and warehouse-region pairs.

2.5 Site Selection Problem

Globalization has enormous impacts on the operations of any company. To be profitable in global markets, companies must optimize their manufacturing and supply-chain operations. In supply-chain (logistics) systems, site selection problem is important since it directly affects transportation and labor costs as well as the speed of moving products from ports to their final destinations. Most of the logistics related costs such as transportation, distribution and product handling are somewhat related to warehouse locations. According to LaLonde and Delaney, transportation costs, which are related to the movements of goods from product origin to storage and to final destination, account for approximately 50% of the total logistics cost, and about 30% of the total logistic costs are due to the direct warehousing costs (cited in Sivitanidou, 1996). Clearly for supply-chain (logistics) systems, site and capacity selection is one of the important decisions, involving cost, credibility and pace, in the long-term planning of a company.

Reliability or credibility as well as speed are also very important. Basically, the distribution process should be as reliable and fast as possible. Especially with the implementation of “just in time” inventory strategies companies are willing not to keep excess inventory before it is needed. Therefore, they are expecting to have flawless (and punctual) logistics networks. According to Strategic Distribution Business Promotion Plan (SDBPP) (2007), some of the Top 100 Importers and Exporters (from Journal of Commerce, 2005) are serving their markets within a range of one to two days, and some of these companies are willing to pay more to save days out of the transportation time.

Under these circumstances, identifying favorable warehouse locations -in terms of cost, credibility and pace in the logistics network- turns out to be a very crucial aspect for retail businesses. The overall supply-chain network should be designed considering the key factors listed above.

2.6 Factors Effecting Site Selection Decisions

This section is going to define cost, proximity, availability and regulation factors which affect warehousing network decisions.

2.6.1 Cost Factors:

Gerry Shear emphasizes the importance of cost factor by stating the transportation cost as "the biggest cost associated with distribution. The cost of outbound distribution to stores is entirely the retailer's responsibility and the placement of the distribution center is a very important factor in managing these costs" (cited in "Site Selection for DC's", 2003). Transportation costs might be a significant element of the entire cost factor; however, there are other cost elements like holding, ordering, shortage costs which form the **total inventory cost**; and labor, facility, administrative, equipment costs which form the **total warehousing cost**. "Logistics Costs and US Gross Domestic Product" (2005) presents the estimates of US business logistic costs for 2002, and states that about 33% of the total logistics costs constitutes inventory-carrying (including warehousing) expenses.

2.6.2 Proximity Factors:

Proximity issues are not so different from the cost factors for selecting the warehouse location. The necessity for being close to certain regions arises due to the need of reducing transportation and/or inventory costs. Companies are willing to locate their warehouses depending on the proximity to the source or the consumer.

2.6.3 Availability Factors:

After cost and proximity factors for selecting warehouse locations, we can talk about availability factors' of certain services and resources. Basically, these constraints include availability of qualified labor, transportation means and specialized services.

2.6.3.1 Availability of Labor,

According to Gil Mayfield, being close to the appropriate working force (class) is the most crucial component for selecting the location of warehouses (cited in “Site Selection”, 2003). Unfortunately, labor availability can change drastically within even short distances. As a result of this, site selection gets an important restriction over most of the available regions. In some cases, companies choose to recruit and train their own work forces due to the difficulties of finding qualified labor around a probable warehouse location. As a result of additional trainings and recruiting processes overall labor cost increases unfavorably. According to Rena Sivitanidou (1996, p. 1261), facility location problems have constraints of both low and high skilled labor, and this has to be satisfied in a given region. We can conclude that defining labor constraints is an essential part for optimization of the warehouse location due to its complex cost, availability and quality variations.

2.6.3.2 Availability of Transportation,

The requirement for means of transportation is simple; warehouses need to be accessed by different types of transportation modes, such as land, water or air shipment. Among these, rail system can play an important role for the selection of warehouse location. In most cases, rail systems offer cheaper and more consistent way of transportation (this statement is questionable regarding to the inconsistencies of the rail system in US). On the other hand, flexibility of an available transportation system is also essential. In other words, inbound and outbound transportation required to be (easily) responsive to changes in shipping locations. As a result, locations which have the access multi-modal transportation happen to be more favorable for some companies.

2.6.3.3 Availability of Services,

Besides availability of skilled labor and transportation means, availability of specialized services can be very important in some logistics network. These are services provided by intermediaries or third party logistics (3PL) providers and include transportation, warehousing and logistic services. The reason for outsourcing is clearly stated by Long (2003): "competitive pressure has made many companies return to their core competencies and outsource functions that others can do better". In other words, if the benefits of outsourcing to another company are greater than the cost of supervising that company, then those services should rather be outsourced.

2.6.4 Regulation Factors:

At this point, we are considering governmental codes that regulate transportation, warehousing and environmental issues. Implementation of free trade zones (FTZ), which lowers general trade barriers and bureaucratic requirements, can be stated as an example for the beneficial regulations. A good reference can be represented from SDBPP (2007); one of the interviewed companies claimed that by using FTZ, they have been saving annually 5% of their inventory cost through postponing duty taxes until selling their products.

Chapter 3

The Proposed Approach

This thesis considers a single company that is planning to optimize its logistics network. We handled the problem by developing a hybrid optimization-simulation model that searches for an optimum or near optimum warehousing network. The simulation part of the model is capable of replicating logistics network of a given company, including its suppliers, ports, warehouses and customer market. We have implemented certain cost, demand and transportation variables into the simulation model which is capable of managing multiple products. The optimization part of the model searches for an optimal networking decision by generating various warehousing scenarios for the simulation model. These scenarios are simulated and their results are compared automatically by the optimization part. In additional to that, modelers are capable of setting certain constraints for warehouse locations and cost parameters via optimization model in order to control the optimization mechanism.

3.1 The Simulation Model

To simulate the logistics network, a logistics template was developed by using Arena Simulation Software. With this Template, we are capable of modeling a wide variety of logistics networks for any given importer company. Below, we mention about the implemented logic behind this template which was used to create the simulation model.

The logistics network model consists of five echelons: customers, regional warehouses (RWH), international warehouses (IWH), ports and suppliers. The hierarchical outline of the model is given in Figure 3.1, and a representative scenario for a logistics network is shown Figure 3.2. According to these figures, each node is connected to one and only one upper node. This implies that at every stage, the order requests will be directed to only one node at the upper stream. Nevertheless, any of these nodes (excluding the final one, customers) might supply multiple lower nodes.

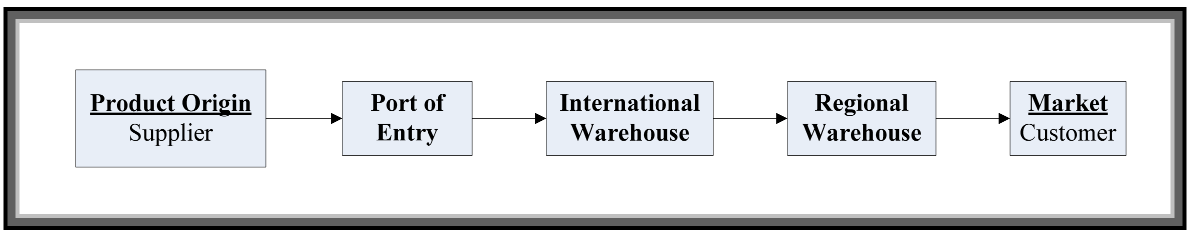

Figure 3.1: Hierarchy of a logistics network

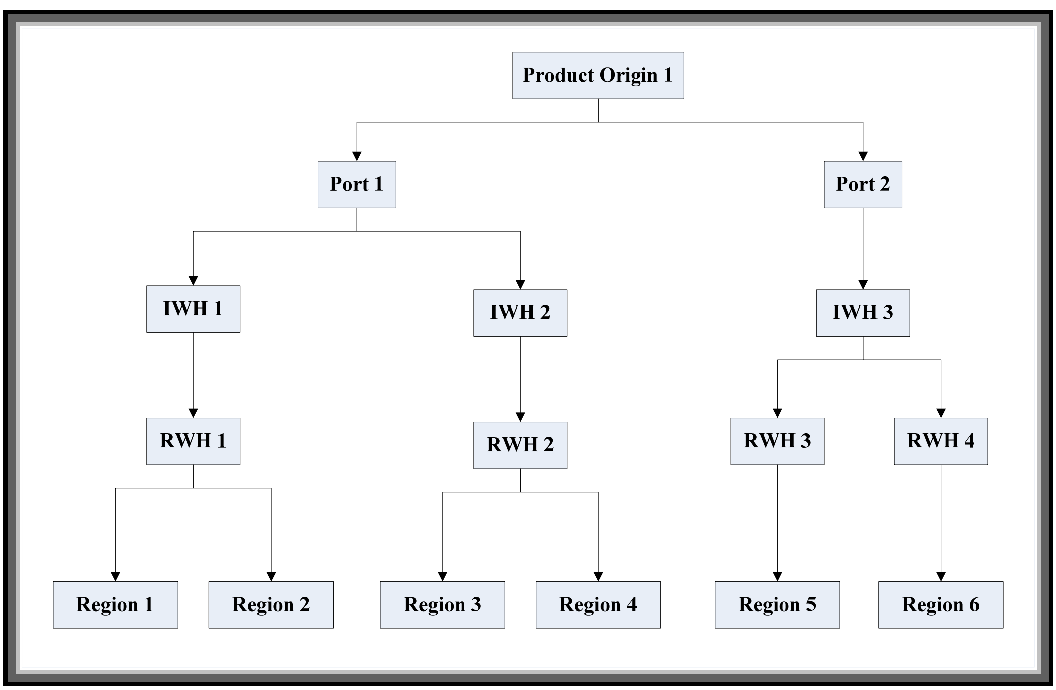

Figure 3.2: Scheme of a representative scenario

The constructed logic behind these nodes is capable of simulating a logistics network, and calculating expenses based on transportation, warehousing and inventory parameters. Figure 3.3 represents the architectural relationships between nodes of a logistics network, and specifies fundamental variables and control parameters associated with it.

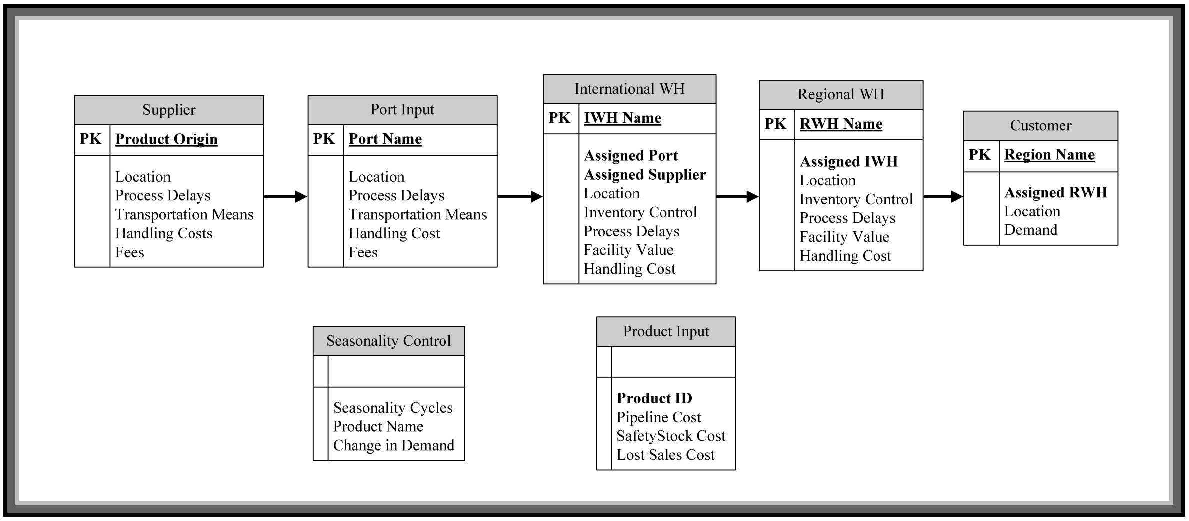

Figure 3.3: Arena module relationships

The following section contains the basic but yet crucial information about the warehousing logic. Detailed information regarding to all nodes (echelons), including product origin, ports, warehouses and regions is given in Appendix D.

3.1.1 Warehousing Logic:

The implemented logic in warehouse objects consists of two sections: supplying demand and controlling inventory. An overview of the supply logic is shown in Figure 3.4. When an order arrives, if the warehouse has enough stock to supply the demand, then the supplying mechanism will be instantly initiated. However, if there is not enough stock to supply the total demand of one or more products, then, depending on the inventory on-hand, these orders are going to be either partially supplied or dismissed completely. When an order is supplied, the equivalent amount of inventory is deducted from both on-hand inventory and inventory position levels. The final stage for this procedure is to prepare a shipment plan which includes type, duration and cost of transportation.

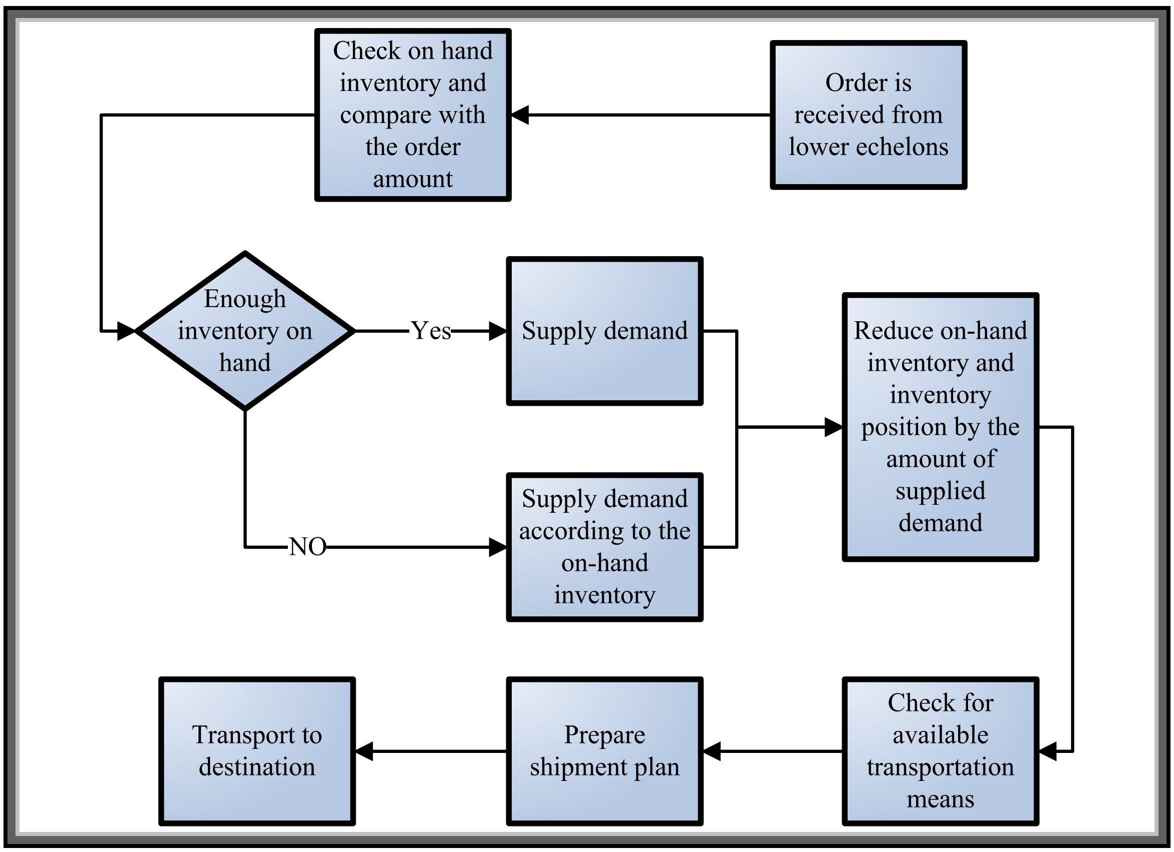

Figure 3.4: Supply logic for warehouses

Every warehouse has its own inventory control policy. A general (r, R) policy, with a safety stock level, is implemented at each warehouse. Basically, inventories will be checked on pre-set review periods, and whenever inventory position goes below re-order level (r), an order will be prepared for an equivalent amount of product to move the

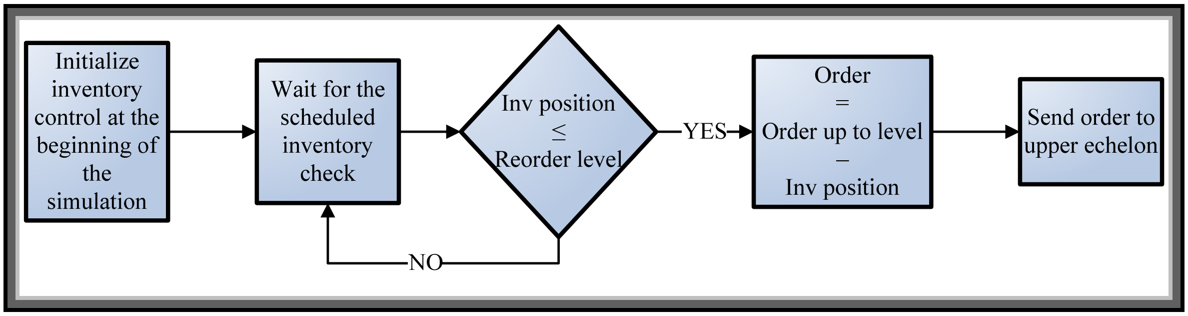

Figure 3.5: Inventory control logic

inventory position to order up to level (R). This process is shown in the Figure 3.5. Within the constructed logistics template, these variables can either be entered manually via each warehouse's dialog box or set to be calculated automatically within the template's logic. The equations used for the calculations are explained below:

Notation for Parameters:

SS (i) – Safety stock for product i (in units of TEUs).

RoL (i) – Re-order level for product i (in units of TEUs).

OuL (i) – Order up to level for product i (in units of TEUs).

Inv (i) – On-hand inventory for product i (in units of TEUs).

IP (i) – Inventory position for product i (in units of TEUs).

c – Correlation factor (accepted to be 0.5).

D (i) – Demand for product i per unit amount of time.

D_i – Demand for product i during review period.

σ_i – Standard deviation of demand for product i.

F – Frequency of shipments.

f – Standard deviation factor.

K – Safety factor (take k = 2 for 98% of no stock-outs).

LT – Lead time for receiving orders (between ordering goods and receipt at destination).

σ – Standard deviation of lead time.

T – Review period.

ST – Safety time.

The following equations are used for the calculations of the safety-stock, re-order and order up to levels for any given warehouse. These equations are based on lead time values between nodes and demand parameters of the lower echelon. For the computation of these proposed inventory parameters, we have implemented two different set of calculation methods as Type-1 and Type-2. The modeler can choose the one that is more suitable for the studied scenario.

Type-1 Calculations[(1)]:

Formula for Safety Stock

$$ST = LT + f \times \sigma \tag{1}$$

$$SS(i) = \sigma_i \times ST \tag{2}$$

Formula for Re-order Level

$$RoL(i) = \frac{LT \times D_i}{T} + SS(i) \tag{3}$$

Formula for Order up to Level

$$OuL(i) = \frac{D_i}{T} + RoL(i) \tag{4}$$

[(1)] This set of calculations is based on Reference 14.

Type-2 Calculations[2]:

Formula for Safety Stock

$$SS(i) = k\sqrt{(LT+F)\times\sigma_i^2 + \left[D(i)\right]^2 \times \sigma^2} \tag{5}$$

Formula for Re-order Level

$$RoL(i) = (LT+F)^c \times D(i) \tag{6}$$

Formula for Order up to Level

$$OuL(i) = RoL(i) + D(i) \tag{7}$$

Note: We have not set frequency of shipments (F) in the logic of the template; therefore, we are going to ignore it from these equations.

Initial inventory position and on-hand inventory levels for both calculation types:

$$Inv(i) = \frac{RoL(i) + OuL(i)}{2} = IP(i) \tag{8}$$

3.1.2 Cost Parameters:

As stated in previous sections, the simulation model is also responsible for cost calculations. The model is designed for the calculations of cost parameters of product origin, port, warehouse, inventory and all transportation costs in between. At the end of each run, the total cost figures will be calculated according to the inputs of cost elements. These proposed elements can be inputted to the model individually or together. The breakdown of cost elements are listed below:

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(2) This set of calculations is based on Reference 10.

Ports & Product Origin	**Warehouses**	**Inventory**	**Transportation**
Handling	Facility	Safety-Stock	Trucking
Taxes	Labor	Pipeline	Rail
Other fees	Equipment	Ordering	Shipping
	Utilities	Shortage	
	Taxes		

Table 3.1: Implemented cost parameters in the simulation model

3.2 Optimization Model

The general optimization problem is based on minimizing the total cost output of the simulation model. In a given scenario, there might be *i* IWHs and *j* RWHs that serve the overall market. Each warehouse is going to be located within a given set of potential regions. If we set each region with a unique ID number, we can input its location as a constraint to the optimization model. If the output of the model that we seek to minimize is Q, the optimization problem can be formally stated as,

$$\min_{IWH1,\ldots,IWHi,RWH1,\ldots,RWHj} E\lfloor Q(IWH_1,\ldots,IWH_i,RWH_1,\ldots,RWH_j\rfloor$$

Subject to,

$$l_1 \le IWH_1 \le u_1 \qquad l_{i+1} \le RWH_1 \le u_{i+1}$$

$$\vdots \qquad\qquad \vdots$$

$$l_i \le IWH_i \le u_i \qquad l_{i+j} \le RWH_6 \le u_{i+j}$$

We use OptQuest Software for the optimization tool for the designed simulation model. This software is exclusively for optimization purposes and it has the capability of operating with Arena models. The principals of OptQuest are summarized in its manual as:

> "The optimization method used by OptQuest evaluates the responses from the current simulation run, analyzes and integrates these with responses from previous simulation runs, and determines a new set of values for the controls, which are then evaluated by running the Arena model. This is an iterative process that successively generates new sets of values for the controls, not all of them improving, but which, over time, provides a highly efficient trajectory to the best solutions. The process continues until some termination criterion is satisfied-usually stopping after a number of simulations or when OptQuest determines the objective value has stopped improving. Its ultimate goal is to find the solution that optimizes (maximizes or minimizes) the value of the model's objective".

This software also allows modelers to set additional constraints for cost parameters and warehouse locations in order to control the optimization criteria. It is used to search for an optimal networking decision by generating multiple warehousing scenarios for the simulation model. By comparing cost outputs of every scenario, OptQuest searches for the lowest-cost logistics network.

Chapter 4

Logistics Network Model

In this chapter, our intention is to represent an example model that is composed of a single importer company. The goal is to optimize this company's logistics network within the continental United States (excluding Alaska and Hawaii). We have come up with a hypothetical company which is importing three different products from Shanghai, China. The average import volumes are accepted as 20, 10 and 30 thousand TEUs per year for Product 1, 2 and 3. In order to point out the status of this Company, we can state that with such a volume of imports, it can be classified in the Top 25 importer/exporter companies in US. Based on the assumed declared values, we came up with the product related inputs such as pipeline, safety-stock and lost sales costs. Detailed information about preparation of Table 4.1 is shown in Appendix A.

	Product 1	**Product 2**	**Product 3**	unit
Declared Value	40	50	30	per cubic foot
Pipeline Cost	56	70	42	per TEU - day
Safety-Stock Cost	67	84	50	per TEU - day
Lost Sales Cost	23000	29000	18000	per TEU

Table 4.1: Product related inputs to the model

Based on the Leachman's report on Port and Modal Elasticity Study, the US market is divided into 19 regions. Detailed information about these Regions and proposed warehousing locations in these Regions are represented in Appendix A. According to this Study, demand levels are proportional to purchasing power of each region. Therefore, import volume distributions are prepared on the basis of per-capita personal incomes by state and state populations. The following table is accepted as a basis for all products and used for the calculation of mean demand levels, which is presented in Table B.6 in Appendix B.

	Region ID	**Region Name**	**% of Total Imports**
1	Region 5	Seattle-Tacoma	4.024
2	Region 6	Oakland	6.629
3	Region 7	LA-LB	11.782
4	Region 8	Minneapolis	3.262
5	Region 9	Kansas City	4.219
6	Region 10	Dallas	4.572
7	Region 11	Houston	5.576
8	Region 12	Memphis	3.765
9	Region 13	Chicago	10.990
10	Region 14	Atlanta	10.323
11	Region 15	Columbus	1.888
12	Region 16	Cleveland	3.807
13	Region 17	Pittsburgh	2.653
14	Region 18	Charlotte	3.220
15	Region 19	Norfolk	2.740
16	Region 20	Baltimore	2.870
17	Region 21	Harrisburg	2.161
18	Region 22	New York	11.229
19	Region 23	Boston	4.290
		Total	100.000

Table 4.2: Import volume distribution by region

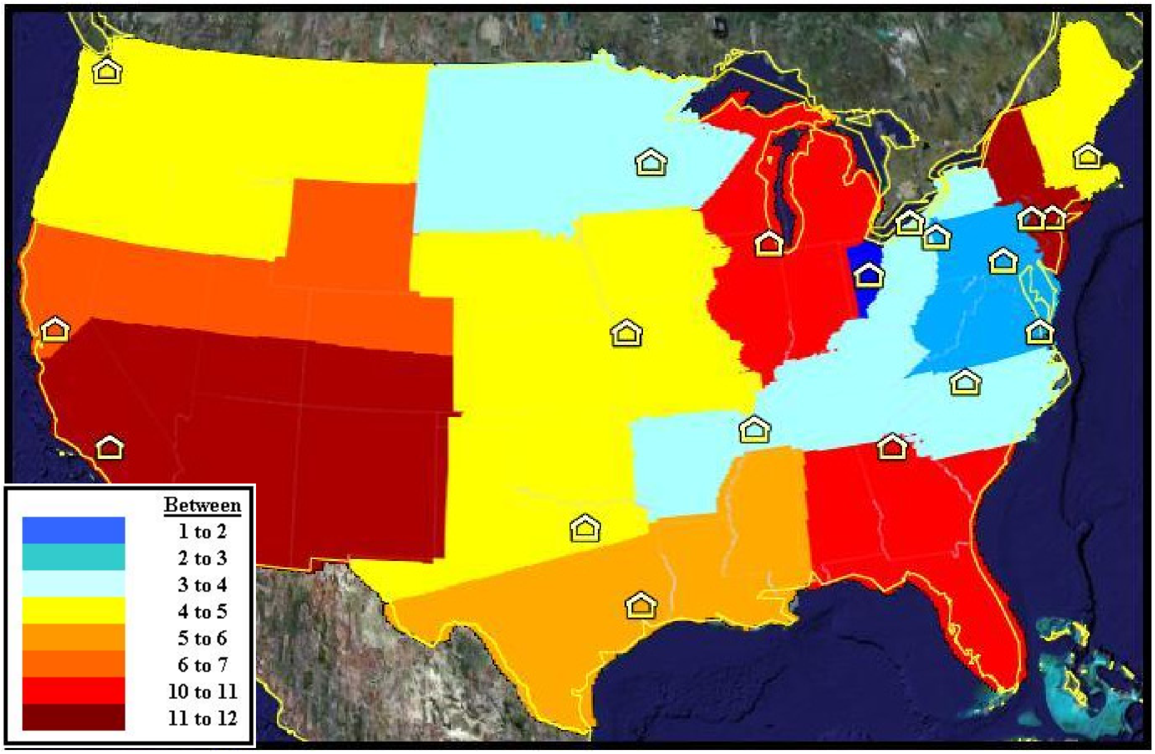

Figure 4.1: Map of import volume distribution[(1)]

Port of entry to the US market is set as either LA-LB or NY-NJ Ports. As the initial stage for storing goods, the Company is accepted to have two international warehouses (IWH) in the site of importation. IWHs are responsible for replenishing inventory of other smaller warehouses, namely regional warehouses (RWH). There are 6 RWHs that are responsible for supplying 19 Regions in US market. Table 4.3 shows the association between IWHs, RWHs and Regions in the proposed logistics network.

(1) All maps presented in this thesis were prepared by Google Earth Software.

		Regions Served (Region ID)	Referred As
IWH 1	RWH 1	5, 6, 7	West Cost Regions
	RWH 2	8, 9, 10, 11	Central-West Regions
IWH 2	RWH 3	13, 15, 16	Central-East Regions
	RWH 4	22, 23	North East Regions
	RWH 5	17, 19, 20, 21	
	RWH 6	12, 14, 18	South East Regions

Table 4.3: Relationships between IWHs, RWHs and Regions

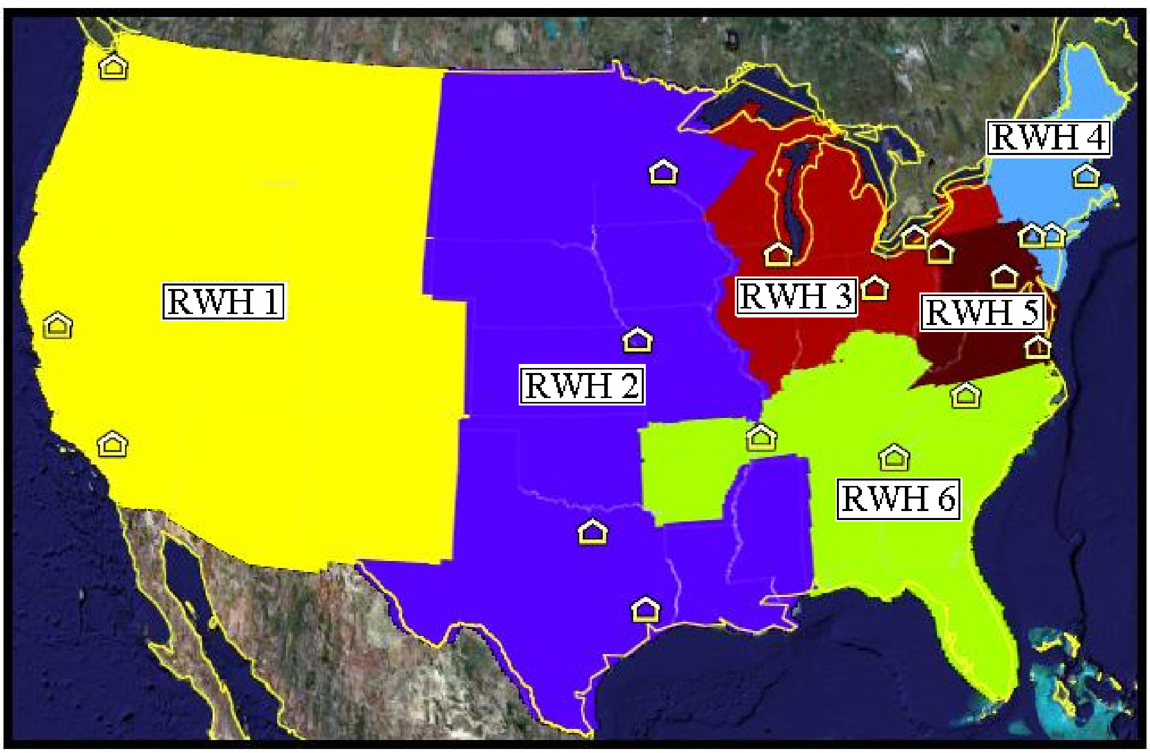

Figure 4.2: US Market divided among RWHs

There is certain cost parameters associated with warehouses such as, facility, handling, ordering and transportation (trucking or rail) costs. These parameters can either be entered into the simulation model by using variable matrices or entered separately through each warehouse interface.

For the proposed scenario, we accepted The Boyd Company's Report (2006) on "A Comparative Operating Cost Analysis for Distribution Warehousing". According to the article "For Cheap Space, Go South" (2006), Boyd Company has studied overall operating costs for distribution centers in 50 different cities in US. They have included costs of labor, utilities, construction/leasing and taxes for a 350,000 square-foot facility that employs 150 non-exempt workers. The article also represents the most and least expensive locations for having a distribution center. Table below shows the annual operating costs retrieved from this article. We have used this information to derive our warehousing cost input to the model. This data is shown in Table B.4 at Appendix B.

	Operating Costs ($)
New York	18,204,373
San Francisco	17,453,387
Los Angeles	17,444,428
Nassau/Suffolk, New York	17,256,767
San Diego	17,154,130
Tulsa, Oklahoma	12,232,331
Chattanooga, Tennessee	12,172,960
Birmingham, Alabama	12,120,971
Mobile, Alabama	11,932,829
Little Rock, Arkansas	11,514,935

Table 4.4: Annual operating costs to own a warehouse

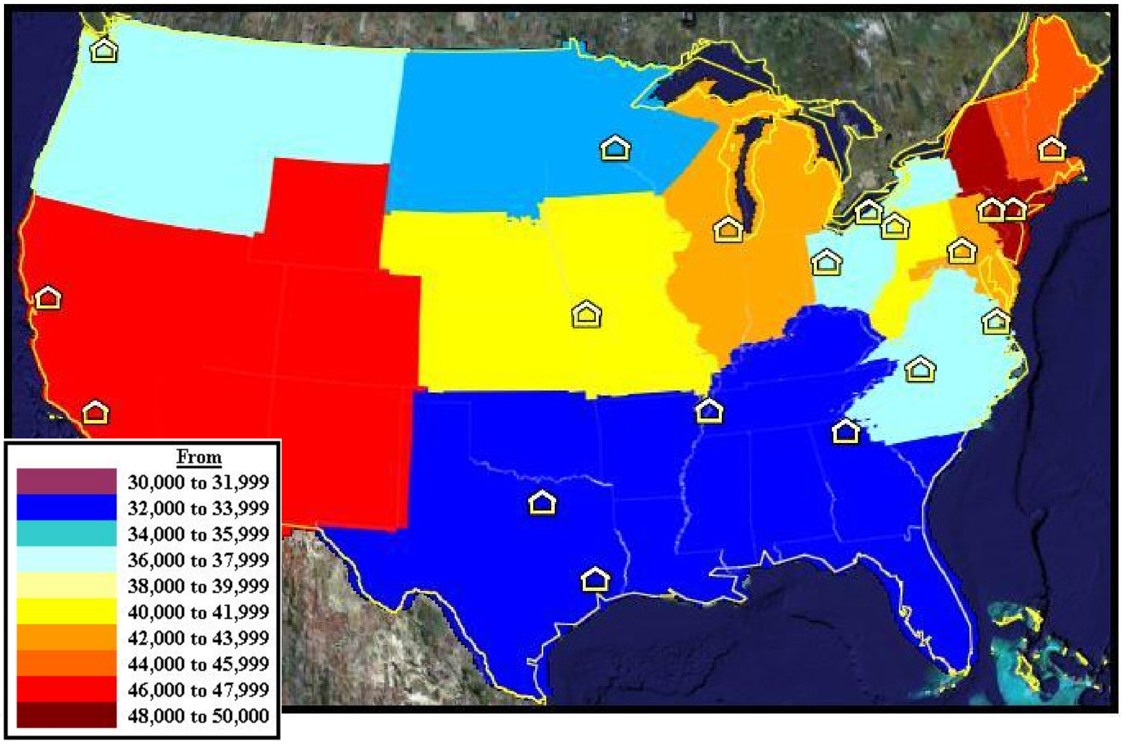

Figure 4.3: Warehousing cost map (legend is based on daily values)

There are two types of transportation methods for inland transportation, rail and trucking:

Rail can only be used between Ports and IWHs. As a basis for preparation of rail transit time inputs, we have accepted "Table 14: Assumed Mean Transit Times for Inland Truck and Rail Movement" from Leachman's (2005) Study. This transit time data represents the overall transportation time including loading at port, unloading and draying at the destination. This data is presented in Table C.2 in Appendix C. The details about preparation of rail cost data is given in the beginning of Appendix C and the results are shown in Table C.3.

Trucking costs, between warehouses, are calculated based on the distance between these nodes which is represented in Table C.5 in Appendix C (light-blue highlighted cells). For 40-foot and 53-foot trucking cost calculations, we have assumed trucking costs as $2 and $2.5 per mile, respectively. This assumption is based on Chang's and Canode's Study on "Economic Impact of the Choctaw Point Intermodal Facility on the Mobile Area" (2003). Chang and Canode stated that their calculations were based on Moffatt & Nichol Engineers' datum on trucking cost which is $1.15 per TEU per mile. Furthermore, we assumed that minimum trucking cost between any two locations, including deliveries in the same region, cannot be lower than $400 for 40-foot and $500 for 53-foot containers. For trucking costs between Ports and IWHs (highlighted with grey), we have followed the same procedure for calculating the rail cost. This is also explained in Appendix C together with the calculations of trucking times.

For the inventory control parameters in warehouses, we used "Type-2 Calculation" method which is mentioned in Chapter 3. For IWHs, we defined safety and correlation factors as 10 and 0.5, respectively; for RWHs, these values were set to 6 and 0.1.

The following Table represents the basic data used in OptQuest software. It shows the suggested regions and possible region sets for warehousing locations. Notice that no region set is given for IWH 1. The location of the IWH 1 was defined as a fixed input for the proposed scenarios. This decision helps to drastically lower the number of possible location combinations and further lower the required optimization time. In additional to that, by considering the proximity of the warehousing location in Region 7 to the LA-LB

Port, we can claim that having an international warehouse in this Region is a fair and valid assumption.

	Suggested Region	**Region Set**	
	(initial feed to OptQuest)	Lower Bound	Upper Bound
IWH 1	7	fixed to 7	
IWH 2	13	12	21 or 23[(3)]
RWH 1	7	5	7
RWH 2	10	8	11
RWH 3	13	13	16
RWH 4	21	15	23
RWH 5	17	15	21
RWH 6	12	12	19

Table 4.5: Location constraints for OptQuest

Based on this Table, we have based the optimization software to minimize the overall cost output of the simulation model. If the output that we seek to minimize is Q, the optimization problem can be formally stated as,

$$\min_{IWH1, IWH2, RWH1, \dots, RWH6} E\left[Q(IWH_1, IWH_2, RWH_1, \dots, RWH_6\right]$$

[(3)] Upper bound for IWH 2 is set to 23 when NY-NJ Port is being utilized.

Subject to,

$$
\begin{array}{lcl}
IWH_1 = 7 & & IWH_1 = 7 \\
12 \le IWH_2 \le 21 & & 12 \le IWH_2 \le 23 \\
5 \le RWH_1 \le 7 & & 5 \le RWH_1 \le 7 \\
\quad\quad . & & \quad\quad . \\
\quad\quad . & \text{or} & \quad\quad . \\
\quad\quad . & & \quad\quad . \\
12 \le RWH_6 \le 19 & & 12 \le RWH_6 \le 19
\end{array}
$$

Chapter 5

Numerical Experimentation and Results

We have based our simulation runs on 730 days of replication length which is approximately 2 years. In order to fully understand the constructed logistics network, we have generated multiple logistics scenarios and simulation-optimization experiments. These experimentations can be described in three sets:

For the first set of experimentations,

We have used the data provided in the previous section and experimented four scenarios based on two different ports together with two transportation options. In order to serve the entire US Market, only one Port was utilized in the 1st and 2nd models. However, for the 3rd and 4th models, 2 Ports were implemented in the logic, in which, LA-LB Port was assigned for supplying IWH 1 and NY-NJ Port was assigned for IWH 2. Within these two groups, we have also constructed separate scenarios by the input of different transportation methods between Ports and IWHs. The Table below shows all these combinations and their results.

Based on the overall output shown in Table 5.1, we may conclude that instead of serving West Cost Regions by RWH 1, we can supply directly from IWH 1, if desired. Moreover, RWH 2 was suggested to be located in Region 10 in order to serve Central-West Regions. This is due to the low transportation cost between IWH 1 and RWH 2, and low warehousing cost at Region 10. These conclusions are also applicable to Model 12 and 13, see Table 5.2 and 5.3.

	Group 1		Group 2	
	Model 1	**Model 2**	**Model 3**	**Model 4**
Port of Entry	LA - LB	LA - LB	LA-LB & NY-NJ	LA-LB & NY-NJ
Mode of Transp.	Rail	Trucking	Rail	Trucking
IWH 1	7	7	7	7
IWH 2	13	12	21	22
RWH 1	7	7	7	7
RWH 2	10	10	10	10
RWH 3	15	15	16	15
RWH 4	16	15	21	21
RWH 5	16	18	19	19
RWH 6	15	12	18	19
Total Cost(1)	1.195293639	1.267873734	1.097312363	1.121152915

Table 5.1: Data of the first set of experimentations(2)

According to the results of Model 1, if consolidation of regional warehouses is allowed, Central-East and Eastern Regions can be supplied by 2 RWHs, instead of 4. By doing this, the overall cost is expected to be lower than indicated unless warehousing costs increase drastically by the increase in turnover ratio. The overall cost for Model 1 is predicted to be higher than Model 3 and 4. This is mainly due to (the cost of mini-land bridge) the inland transportation cost between LA-LB Port and IWH 2. As the primary mode of

(1) The unit of total cost is in billions of dollars, throughout this Chapter
(2) Optimal assignments of IWHs and RWHs to regions

transportation was rail, the goods are transported by rail between Port and IWH 2; and direct-trucking with 40-foot containers between Port and IWH 1.

Model 2 was prepared with a slight modification on Model 1. Instead of utilizing multiple transportation methods through the inland distribution, only trucking was allowed for Model 2. Together with this modification, cross-docking to 53-foot containers was also permitted for trucking between the Port and IWHs (normally, it is only allowed between downstream echelons, starting from IWHs). As expected, the overall logistics cost was calculated to be higher than the previous model. This is mainly because of the high trucking cost (compared to rail) even though the goods were allowed to be consolidated into 53-foot containers. As a result, proximity between Port and IWHs became more crucial and Region 12 was proposed as the location of IWH 2. When it comes to the locating RWHs, warehousing cost also becomes an important factor together with transportation cost. Therefore, RWH 3, 4 and 5 were proposed to be located at closer and cheaper locations. As the last comment on Model 2, we can state that, South East Regions can be supplied directly from IWH 2 instead of operating another RHW, if desired.

By adding another port to the model, the expected logistics cost decreases drastically together with the change in the structure of logistics networks. First of all, even the transportation method was set to rail between Ports and IWHs, only trucking has been used due to not having rail service in between these nodes (it was also redundant to send goods to distant locations). In Model 1, the warehouses that supply eastern regions tend to be closer to the LA-LB Port. However, in Model 3, these warehouses are located closer to NY-NJ Port; and mainly they in regions which offer cheaper warehousing. If consolidation of warehouses is allowed, a modification can be made to the logistics network by supplying Region 22 and 23 directly from IWH 2.

The difference between Model 3 and Model 4 is the transportation methodology. By considering proposed warehousing locations for Model 3, we figure out that the proposed transportation method between the Ports and IWHs was trucking with 40-foot containers. For Model 4, this was trucking with 53-foot containers. Despite the fact that trucking with 53-foot containers is generally cheaper than trucking with 40-foot's, Model 4 suggests locating IWH 2 to Region 22, where warehousing cost is high. When we analyzed this abnormality, we noticed that there was a glitch in the 40-foot trucking costs of NY-NJ Port and IWH 2 pair. This difference is in favor of transporting goods with 40-foot trucking between NY-NJ Port and Region 21, and 53-foot trucking between NY-NJ Port and Region 22. Therefore, the proposed logistics network formed accordingly.

For the second set of experimentations,

Two modifications were made on these models. The first one is the change of Port from LA-LB to NY-NJ. The second one is the implementation of a set of constraints to the objective function of the OptQuest model. "Type A" models were constructed based on this new set of constraints which is restricting to have more than one RWH at any given region. There are also "Type B" models which are practically the same as the previous set. The results are given in Table 5.2 and 5.3 below.

	Model 1	Model 12	
Constraints	**Type-B**	**Type-A**	**Type-B**
Port of Entry	LA - LB	NY- NJ	NY- NJ
Mode of Transp.	Rail	Rail	Rail
IWH 1	7	7	7
IWH 2	13	21	21
RWH 1	7	7	7
RWH 2	10	10	10
RWH 3	15	16	16
RWH 4	16	21	21
RWH 5	16	19	16
RWH 6	15	18	19
Total Cost	1.195293639	1.186357251	1.184473355

Table 5.2: Data of the second set of experimentations, Group 1[(3)]

Before interpreting the data provided for this experimentation set, we need to keep in mind that 60% of the overall market is supplied by the IWH 2, and the rest is by IWH 1. Therefore, in any given scenario, we are expecting that being closer to the high demand areas will be more favorable regarding to the overall cost of the logistics network. When we solely compare the total cost of Model 1 and Model 12-B, we notice that serving the entire Market through NY-NJ Port is more desirable (At this point, note that even though we have fixed the location of the IWH 1, the latter scenario is more promising than the first one on account of the given input data). This proposition is also valid for the Model 2 and Model 13-B pair.

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(3) Optimal assignments of IWHs and RWHs to regions

	Model 2	Model 13	
Constraints	**Type-B**	**Type-A**	**Type-B**
Port of Entry	LA - LB	NY- NJ	NY- NJ
Mode of Transp.	Trucking	Trucking	Trucking
IWH 1	7	7	7
IWH 2	12	22	21
RWH 1	7	7	7
RWH 2	10	10	10
RWH 3	15	15	16
RWH 4	15	21	21
RWH 5	18	19	16
RWH 6	12	18	19
Total Cost	1.267873734	1.259596291	1.185321453

Table 5.3: Data of the second set of experimentations, Group 2[(4)]

As we stated before, the sole difference between Type-A and Type-B models is the restriction of locating multiple RWHs in any given region. By comparing the proposed optimum warehousing locations, we observe that restricted models consider distributing warehouses to the neighboring, low-cost regions. The effect of this restriction on the cost output of the Model 12 is an increase of 0.16%; while, for Model 13, it is around 6.27%.

For the third set of experimentations,

We have fixed the port of entry to LA-LB Port and mode of transportation to “rail” option (between Port and IWHs). With this set of experimentation, we intend to focus on warehousing cost and demand factors of the model. We defined two-level interactions.

(4) Optimal assignments of IWHs and RWHs to regions

Level-1 values are based on the original input data that were presented in Chapter 4; while another set of data was derived for Level-2. Representative values for these levels are shown in Table 5.4 and 5.5, and the actual inputs for regional demand are shown in Table B.5 and B.7 in Appendix B.

			% of Total Imports	
	Region ID	**Region Name**	**Level-1**	**Level-2**
1	Region 5	Seattle-Tacoma	4.024	10.323
2	Region 6	Oakland	6.629	2.870
3	Region 7	LA-LB	11.782	4.290
4	Region 8	Minneapolis	3.262	3.220
5	Region 9	Kansas City	4.219	10.99
6	Region 10	Dallas	4.572	3.807
7	Region 11	Houston	5.576	1.888
8	Region 12	Memphis	3.765	4.572
9	Region 13	Chicago	10.990	2.161
10	Region 14	Atlanta	10.323	5.576
11	Region 15	Columbus	1.888	4.219
12	Region 16	Cleveland	3.807	11.782
13	Region 17	Pittsburgh	2.653	3.765
14	Region 18	Charlotte	3.220	3.262
15	Region 19	Norfolk	2.740	11.229
16	Region 20	Baltimore	2.870	2.740
17	Region 21	Harrisburg	2.161	6.629
18	Region 22	New York	11.229	2.653
19	Region 23	Boston	4.290	4.024
		Total	100.000	100.000

Table 5.4: Import volume distribution by region for both levels
(Initial values were altered randomly to prepare the secondary values)

			Warehousing Cost	
	Region ID	**Region Name**	**Level-1**	**Level-2**
1	Region 5	Seattle-Tacoma	37,000	46,250
2	Region 6	Oakland	47,800	35,850
3	Region 7	Los Angeles	47,800	35,850
4	Region 8	Minneapolis	34,000	42,500
5	Region 9	Kansas City	40,000	30,000
6	Region 10	Dallas	33,500	41,875
7	Region 11	Houston	32,700	40,875
8	Region 12	Memphis	33,400	41,750
9	Region 13	Chicago	43,000	32,250
10	Region 14	Atlanta	33,200	41,500
11	Region 15	Columbus	37,000	46,250
12	Region 16	Cleveland	37,000	46,250
13	Region 17	Pittsburgh	40,000	30,000
14	Region 18	Charlotte	36,000	45,000
15	Region 19	Norfolk	36,000	45,000
16	Region 20	Baltimore	42,000	31,500
17	Region 21	Harrisburg	42,000	31,500
18	Region 22	New York	49,900	37,425
19	Region 23	Boston	45,000	33,750

Table 5.5: Daily warehousing cost for both levels ($)

Note: In order to prepare secondary inputs, we have modified the initial data. Warehousing cost values greater than 39999 were decreased by 25%; and those were less than 40000 were increased by 25%.

	Model 1	Model 5	Model 7	Model 9
Demand	Level-1	Level-2	Level-1	Level-2
Warehousing	Level-1	Level-1	Level-2	Level-2
IWH 1	7	7	7	7
IWH 2	13	13	13	13
RWH 1	7	6	7	7
RWH 2	10	10	9	9
RWH 3	15	16	13	13
RWH 4	16	15	17	17
RWH 5	16	16	17	17
RWH 6	15	15	13	13
Total Cost	1.195293639	1.221993397	1.157151481	1.183248146

Table 5.6: Data of the third set of experimentations

By comparing Model 1 and Model 5, we observe that the import volume distribution has a significant effect on the logistics network. The alterations in locations of RWH 1, RWH 3 and RWH 4 can be presented as convincing proofs for this argument. As high demand density regions change form one model to another, RWHs tend to be located closer to these regions. This pattern can be seen in Figures 5.1 and 5.2. The Regions in these maps are colored based on the import volume distribution (percentage of demand by region).

Changes in warehousing cost also affect the optimum logistics network. Basically, when warehousing cost in a given region is increased, the model tends to locate the warehouse in neighboring regions. This pattern can be observed in Figures 5.3 and 5.4. The locations of IWH 1, IWH 2 and RWH 1 did not change from Model 1 to Model 7 due to making these locations more favorable in terms of warehousing cost.

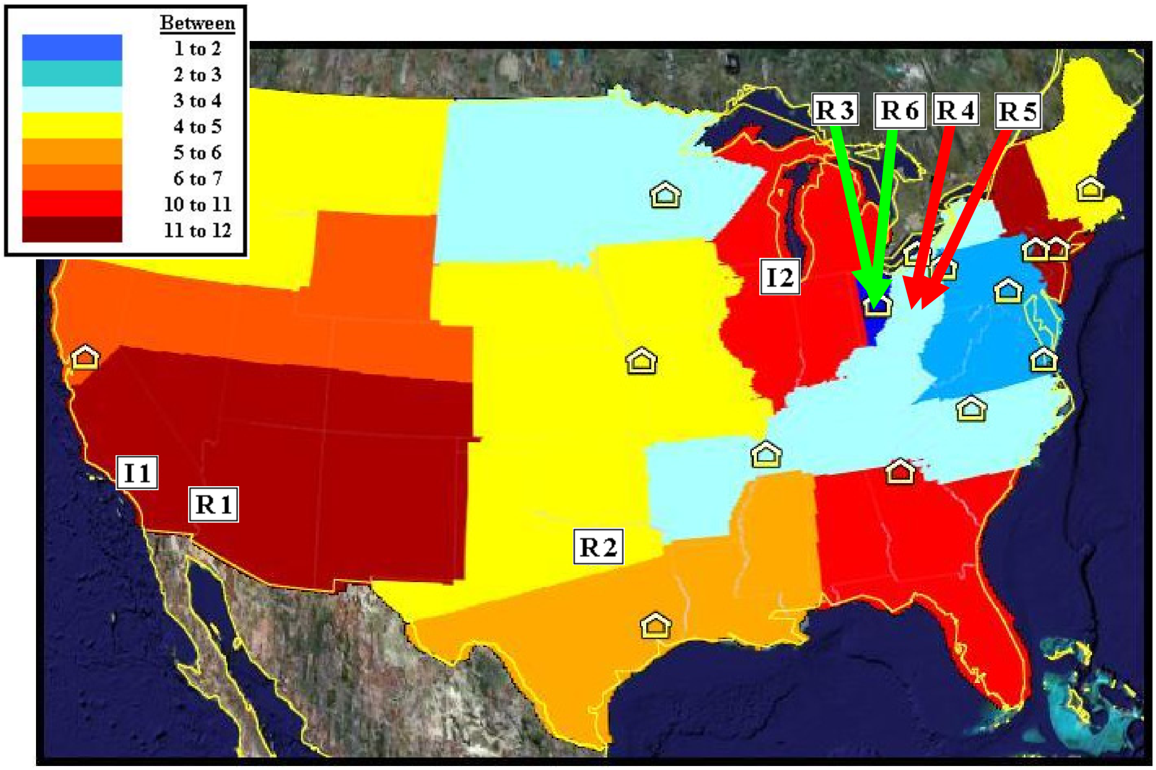


Figure 5.1: Proposed warehouse locations of Model 1, with level-1 demand mapping

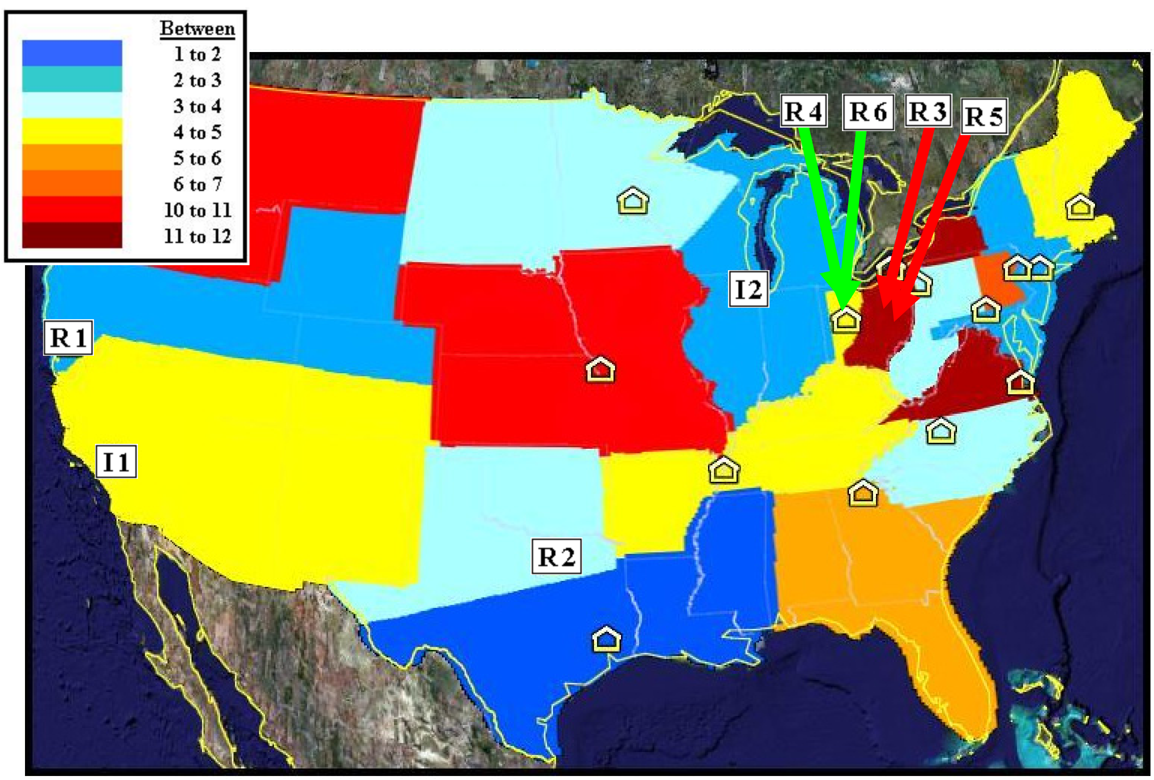


Figure 5.2: Proposed warehouse locations of Model 5, with level-2 demand mapping

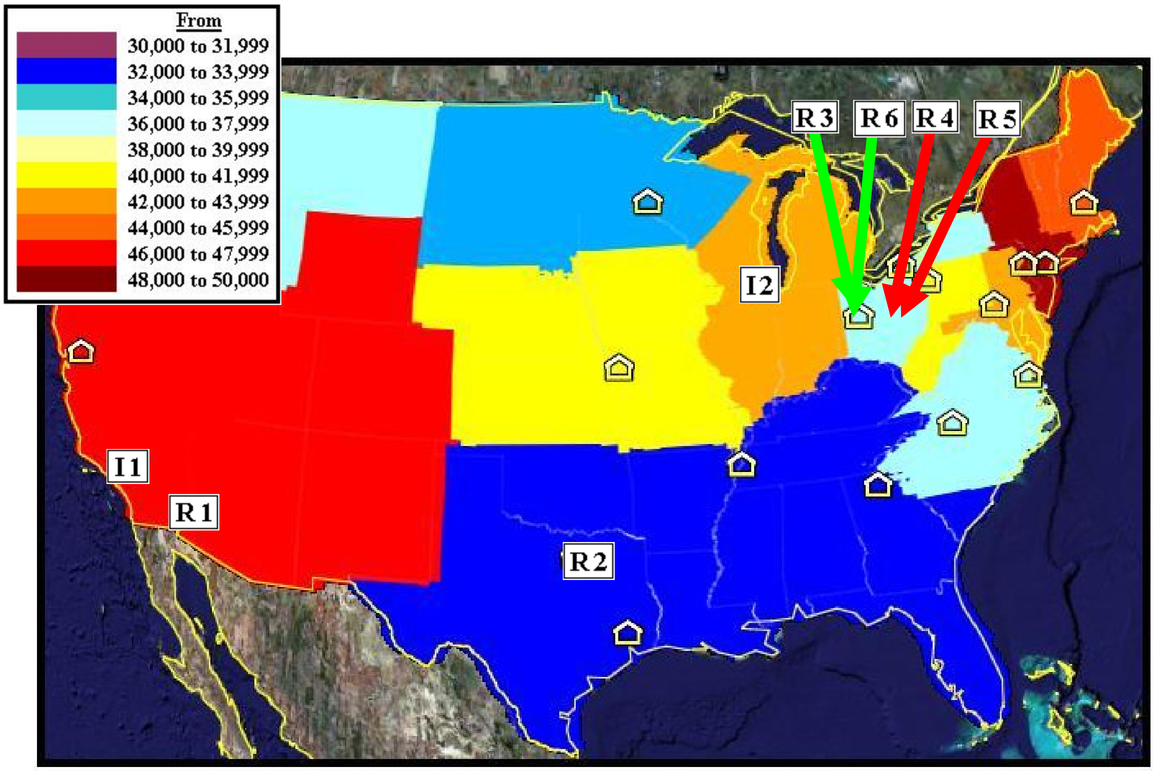


Figure 5.3: Proposed warehouse locations of Model 1, with level-1 WH cost mapping

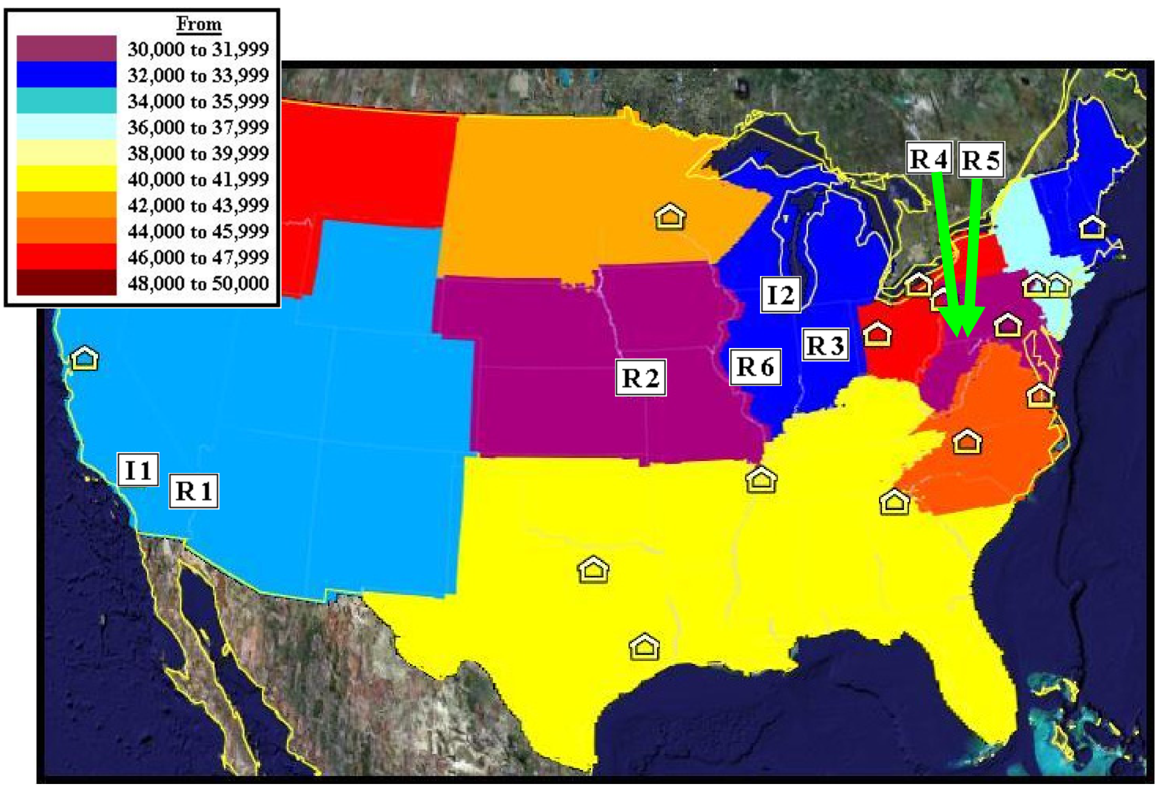


Figure 5.4: Proposed warehouse locations of Model 7, with level-2 WH cost mapping

Chapter 6

Conclusion and Future Work

For this thesis, we have focused our attention on the logistics networks of an importer company. The objective was to develop a tool to help companies in making their warehouse location decisions and understand certain factors that has crucial effect on this decision. We have developed a simulation template for Arena which is capable of modeling most of the important aspects of this logistics network which is consisting of ports, international warehouses, regional warehouses and customer market. OptQuest Software was linked to the simulation model to solve the optimization problem. The objective function is seeking an optimum warehouse networking solution that minimizes the overall cost of the logistics network. We have analyzed the effect of certain factors on the optimization of logistics networks, such as, port of entries, transportation means, import volume distributions and warehousing costs.

In most of the logistics network solutions, we observed that the warehousing location assignments follow a branching pattern starting from the port of entry and stretching towards downstream echelons. The segments of these branches, meaning distance between Port-IWH or IWH-RWH pairs, get longer or shorter depending on the transportation cost inputs of the model. Basically, in order to minimize the overall transportation cost, the optimization model searches a solution to balance the cost ratio between these segments.

As a big portion of the imported goods is being consumed in Eastern Regions through IWH 2, using only LA-LB Port and then supplying these Regions by mini-land bridge drastically increases the total cost of the model. According to the data used in the model, it could be advised to utilize either two ports and supply each IWH separately; or, at least, set NY-NJ Port as the only port of entry.

According to the proposed model and its inputs, warehousing cost and import volume distribution appear to be important factors for selecting warehouse locations in the logistics network. If there are multiple potential neighboring regions, the optimization model normally chooses the low-cost region. However, when these regions are similar to each other according to the warehousing cost, the model seeks for a location which is closer to the high-demand regions.

6.1 Future Work

Even though this tool is capable of handling multiple scenarios without any change in its logic, we can still suggest additional improvements and modifications for further, more detailed studies. In this section, we are going to mention about these suggestions starting from upstream echelons to downstream echelons.

6.1.1 Product Origin:

- Vessel scheduling.
- Loading and unloading processes that includes resources.

6.1.2 Ports:

- Simulating congestion in and around the port area. This would be one of the most crucial improvements in the logic due to its severe effect on retrieving containers from the port and transporting them to required places, on time.
- Including processes that effect transit time and require certain resources. For example, container loading/unloading, security checks, movements inside the port.
- Vessel and rail scheduling.
- Implementing operation hours.
- Utilization of services like customs house brokers and simulating their optional effects on the system.
- Leaving Port as a variable; so that the port of entry can also be optimized together with the warehousing network.

6.1.3 Warehouses:

- Adding structure constraints that will be used to keep warehouses in certain limits. This approach might be helpful for restraining the model to come up with more realistic warehouse capacity results.
- Including value added processes and their effect on logistics networks.
- Some other way of inputting warehousing cost that might be based on the amount of inventory or turnover ratio.
- Implement other inventory control policies such as economic order quantity with reorder level and safety-stock.

6.1.4 Customers (Regions):

- Ordering mechanism should be relaxed by implementing various demand distributions and ordering intervals.
  - Allowing triangular distribution for entering demand quantities this provides a better fit to the ordering logic.
  - Instead of generating demand daily, other options should be presented such as weekly or every other day.

6.1.5 General Suggestions:

- Instead of having a pull system, in which supply is triggered by the amount of demand, implement a combination of pull and push system, in which goods are pushed to the market.
- Include the effects of changes when goods are being transferred from one transportation method to another. For example, delays between unloading containers from train and loading them to trucks.
- Implementing emergency scenarios, backup plans. Lets say when rail service is down, can you transport goods by trucking; or, if a certain warehouse cannot supply demand of the lower echelon, can it be supplied from another location.

References

[1] Anderberg, M.R. *(1973). Cluster Analysis for Applications.* New York: Academic Press.

[2] Baumol, W. J. & Wolfe, P. (1958). *A Warehouse-Location Problem. Operations Research, 6, 2,* 252-263. Retrieved on July 29, 2007 from J-Stor.

[3] Chang, S. & Canode, S. (2003, January). Economic Impact of the Choctaw Point Intermodal Facility on the Mobile Area. Retrieved on April, 11 2008 from http://www.asdd.com/pdf/ASDReport1.pdf

[4] For Cheap Space, Go South (2006, January). Retrieved on September, 23 2008 from http://outsourced-logistics.com/global_markets/outlog_story_7674/

[5] Gourdin, K. N. (2006). *Global Logistics Management: A Competitive Advantage for the 21st Century*. Second Edition. Wiley, John & Sons, Incorporated.

[6] Jain, A.K., Dubes, R.C. (1988). *Algorithms for Clustering Data*. Englewood Clifs, New Jersey: Prentice Hall.

[7] Khumawala, B. M. (1972, August). An Efficient Branch and Bound Algorithm for the Warehouse Location Problem. *Management Science, 18,* B718-B731.

[8] Ko, H. J., Ko, C. S. & Kim, T. (2006). A hybrid optimization/simulation approach for a distribution network design of 3PLS. *Computers & Industrial Engineering, 50,* 440-449.

[9] LaLonde, J. B. & Delaney, R. V. (1993). *Trends in Warehousing Costs,* Management and Strategy Warehousing Education and Research Council, 1100 Jorie Blvd, Suite 170, Oak Brook, IL 60521.

[10] Leachman, R. C. (2005, September). Final Report Port and Modal Elasticity Study. Retrieved on February, 10 2008 from http://www.scag.ca.gov/goodsmove/pdf/FinalElasticityReport0905.pdf

[11] Logistics Costs and U.S. Gross Domestic Product. (2005, August). Retrieved on January, 25 2008 from http://ops.fhwa.dot.gov/freight/freight_analysis/econ_methods/lcdp_rep/index.htm

[12] Long, D. (2003, July). *International Logistics: Global Supply Chain Management.* First Edition. Springer.

[13] Melachrinoudis, E. & Min, H. (2007). Redesigning a warehouse network. European *Journal of Operation Research, 176,* 210-229.

[14] Rawat, M. (2005). Analysis of Safety Stock Policies in Supply Chains. A thesis submitted to Graduate School-New Brunswick. Rutgers, State University of New Jersey.

[15] Site Selection for DC's. (2000, May). *Chain Store Age, 79,* 138.

[16] Sivitanidou, R. (1996). Warehouse and Distribution Facilities and Community Attributes: An Empirical Study. *Environment and Planning, 25,* 1261. Retrieved on March 10, 2007 from IEEE.

[17] Strategic Distribution Business Promotion Plan (SDBPP) Final Presentation. (2007, May).

[18] Williams, E. J. & Gunal, A. (2003). Supply chain simulation and analysis with simflex. *Simulation Conference, 2003, Proceedings of the 2003 Winter, 1,* 231-237.

Appendix A

Calculations for Table 4.1:

- 1 TEU is equal to 1,169 cu foot.
- As an assumption stated by Leachman (2005), pipeline and warehouse inventories are valued 25% and 50% more than declared values to Customs, respectively.
- Annual interest rate is accepted as 35%.
- Lost sales cost is assumed to be 1/3 of the commodity value at warehouse.

Pipeline Cost (daily) = 1.25 x 1169 x Declared Value x 0.35 / 365

Safety-Stock Cost (daily) = 1.50 x 1169 x Declared Value x 0.35 / 365

Lost Sales Cost = 1.50 x 1169 x Declared Value / 3

Regions and assumed warehousing sites are as follows:

1) Seattle-Tacoma Region: including Washington, Oregon, Idaho and Montana Warehousing location is assumed to be in Fife, WA.
2) Oakland Region: including Wyoming, 50% of Colorado, 67% of Utah, 34% of California, and 33% of Nevada. Warehousing location is assumed to be in Tracy, CA.

3) LA-LB Region: including Arizona, New Mexico, 66% of California, 67% of Nevada, 33% of Utah, and 50% of Colorado. Warehousing location is assumed to be in Ontario, CA.

4) Minneapolis Region: including North Dakota, South Dakota, Minnesota and 50% of Wisconsin. Warehousing location is assumed to be in Rosemount, MN.

5) Kansas City Region: including Kansas, Nebraska, Iowa and Missouri. Warehousing location is assumed to be in Lenexa, KS.

6) Dallas Region: including Oklahoma and 50% of Texas. Regional distribution center assumed to be in Midlothian, TX.

7) Houston Region: including Louisiana, Mississippi and 50% of Texas. Warehousing location is assumed to be in Baytown, TX.

8) Memphis Region: including Arkansas, Tennessee and Kentucky. Warehousing location is assumed to be in Millington, TN.

9) Chicago Region: including Illinois, Indiana, Michigan and 50% of Wisconsin. Warehousing location is assumed to be in Joliet, IL.

10) Atlanta Region: including Alabama, Georgia, Florida and 50% of South Carolina. Warehousing location is assumed to be in Duluth, GA.

11) Columbus Region: including 50% of Ohio. Warehousing location is assumed to be in Springfield, OH.

12) Cleveland Region: including 50% of Ohio and 25% of New York. Warehousing location is assumed to be in Chagrin Falls, OH.

13) Pittsburgh Region: including West Virginia and 50% of Pennsylvania. Warehousing location is assumed to be in Beaver Falls, PA.

14) Charlotte Region: including North Carolina and 50% of South Carolina. Warehousing location is assumed to be in Salisbury, NC.

15) Norfolk Region: including Virginia. Warehousing location is assumed to be in Suffolk, VA.

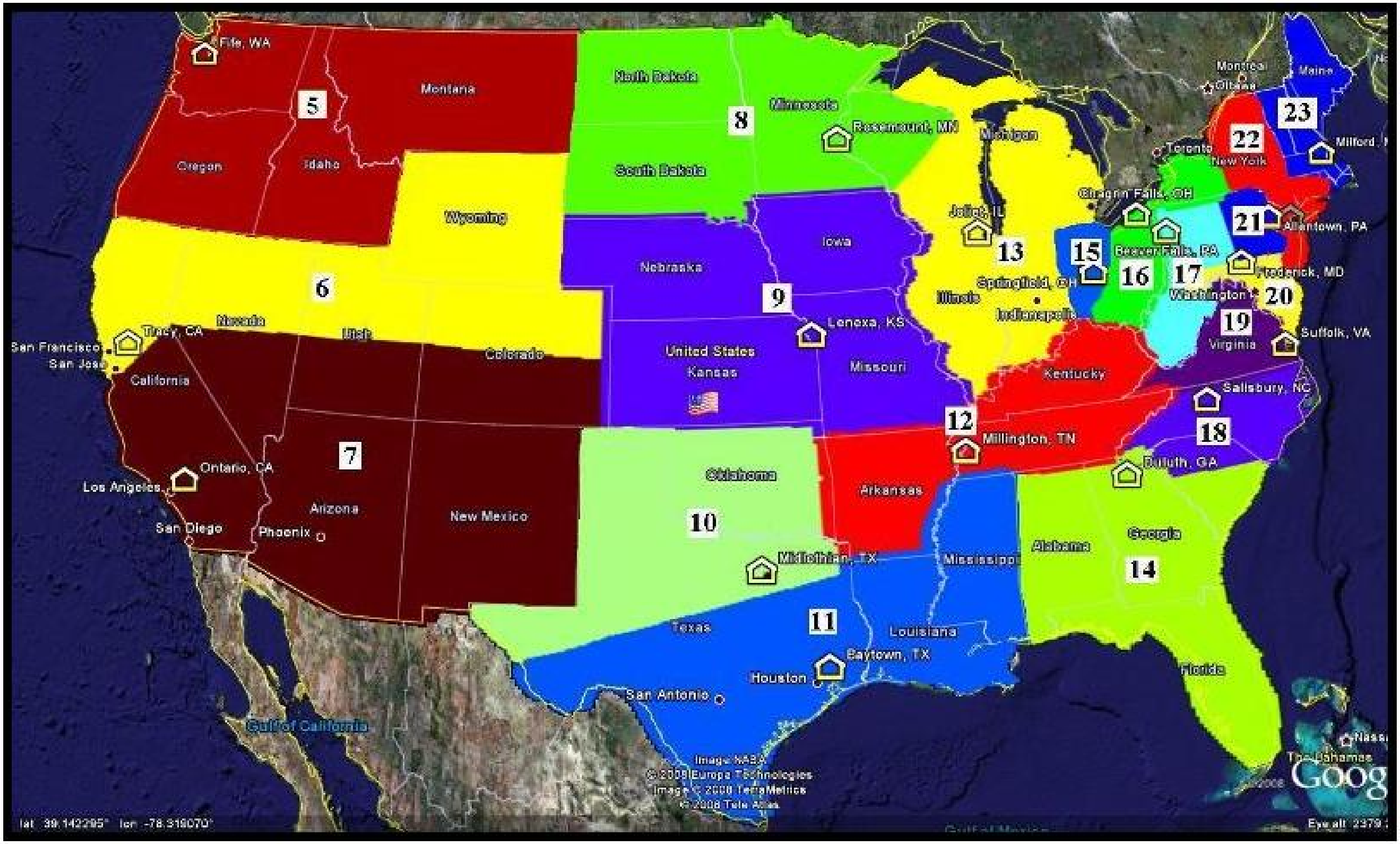
16) Baltimore Region: including Maryland, DC and Delaware. Warehousing location is assumed to be in Frederick, MD.

17) Harrisburg Region: including 50% of Pennsylvania. Warehousing location is assumed to be in Allentown, PA.

18) New York Region: including New Jersey, Connecticut and 75% of New York. Warehousing location is assumed to be in East Brunswick, NJ.

19) Boston Region: including Rhode Island, Massachusetts, New Hampshire, Vermont and Maine. Warehousing location is assumed to be in Milford, MA.

Figure A.1: Map of Regions and warehouse locations



Appendix B

Table B.1: Transit time input between Shanghai, China and US Ports (days)

TDistOrigin	LA-LB	NY-NJ	SA	SE-TA
Shanghai_Type_1	14	26	28	15
Shanghai_Type_2	14	28	26	15

Table B.2: Shipping cost input from Shanghai, China to US Ports ($)

ShippingOriginCost	LA-LB	NY-NJ	SA	SE-TA
Shanghai_Type_1	3500	4000	4500	3600
Shanghai_Type_2	3500	4500	4000	3600

Table B.3: Transit time inputs at Ports (days)

	Shanghai	LA-LB	NY-NJ	SA	SE-TA
Delay per Order	1	3	3	3	3
Std Dev of Lead Time	5	2	2	2	2

Note: Facility values are included in handling costs; therefore, they are not shown separately in Table B.4 and Table B.5.

Note: The description about level-1 and level-2 inputs is given in Third Set of Experimentations in Chapter 5.

Table B.4: Warehouse related inputs for the initial scenario (level-1 inputs)
(This data is valid for both RWHs and IWHs)

LocVar	Location Number	Facility Value ($)	Delay per Order (days)	Ordering Cost ($)	Handling Cost ($)
Seattle-Tacoma	5	0	0.3	300	37000
Oakland	6	0	0.5	300	47800
Los Angeles	7	0	0.3	300	47800
Minneapolis	8	0	0.4	300	34000
Kansas City	9	0	0.2	300	40000
Dallas	10	0	0.2	300	33500
Houston	11	0	0.1	300	32700
Memphis	12	0	0.2	300	33400
Chicago	13	0	0.2	300	43000
Atlanta	14	0	0.1	300	33200
Columbus	15	0	0.3	300	37000
Cleveland	16	0	0.1	300	37000
Pittsburgh	17	0	0.4	300	40000
Charlotte	18	0	0.3	300	36000
Norfolk	19	0	0.4	300	36000
Baltimore	20	0	0.2	300	42000
Harrisburg	21	0	0.2	300	42000
New York	22	0	0.4	300	49900
Boston	23	0	0.1	300	45000

Table B.5: Warehouse related inputs for the secondary scenario (level-2 inputs)

LocVar	Location Number	Facility Value ($)	Delay per Order (days)	Ordering Cost ($)	Handling Cost ($)
Seattle-Tacoma	5	0	0.3	300	46250
Oakland	6	0	0.5	300	35850
Los Angeles	7	0	0.3	300	35850
Minneapolis	8	0	0.4	300	42500
Kansas City	9	0	0.2	300	30000
Dallas	10	0	0.2	300	41875
Houston	11	0	0.1	300	40875
Memphis	12	0	0.2	300	41750

Table B.5 Continues

Chicago	13	0	0.2	300	32250
Atlanta	14	0	0.1	300	41500
Columbus	15	0	0.3	300	46250
Cleveland	16	0	0.1	300	46250
Pittsburgh	17	0	0.4	300	30000
Charlotte	18	0	0.3	300	45000
Norfolk	19	0	0.4	300	45000
Baltimore	20	0	0.2	300	31500
Harrisburg	21	0	0.2	300	31500
New York	22	0	0.4	300	37425
Boston	23	0	0.1	300	33750

Table B.6: Mean values for daily demand for the initial scenario (level-1 inputs) (variance is accepted as 1 TEU/day)

	Region	**Product 1**	**Product 2**	**Product 3**	
1	Seattle-Tacoma	2	1	3	
2	Oakland	4	2	5	
3	LA-LB	6	3	10	
4	Minneapolis	2	1	3	
5	Kansas City	2	1	3	
6	Dallas	3	1	4	
7	Houston	3	2	5	
8	Memphis	2	1	3	
9	Chicago	6	3	9	
10	Atlanta	6	3	8	
11	Columbus	1	1	2	
12	Cleveland	2	1	3	
13	Pittsburgh	1	1	2	
14	Charlotte	2	1	3	
15	Norfolk	2	1	2	
16	Baltimore	2	1	2	
17	Harrisburg	1	1	2	
18	New York	6	3	9	
19	Boston	2	1	4	
	Total	**55**	**29**	**82**	**TEUs/day**
		20075	**10585**	**29930**	**TEUs/year**

Table B.7: Mean values for daily demand for the secondary scenario (level-2 inputs) (variance is accepted as 1 TEU/day)

	Region	**Product 1**	**Product 2**	**Product 3**	
1	Seattle-Tacoma	6	3	8	
2	Oakland	2	1	2	
3	LA-LB	2	1	4	
4	Minneapolis	2	1	3	
5	Kansas City	6	3	9	
6	Dallas	2	1	3	
7	Houston	1	1	2	
8	Memphis	3	1	4	
9	Chicago	1	1	2	
10	Atlanta	3	2	5	
11	Columbus	2	1	3	
12	Cleveland	6	3	10	
13	Pittsburgh	2	1	3	
14	Charlotte	2	1	3	
15	Norfolk	6	3	9	
16	Baltimore	2	1	2	
17	Harrisburg	4	2	5	
18	New York	1	1	2	
19	Boston	2	1	3	
	Total	**55**	**29**	**82**	**TEUs/day**
		20075	**10585**	**29930**	**TEUs/year**

Appendix C

The preparation of Table C.3,

We retrieved transportation rates from "Table 18: Transportation Rates per Cubic Foot" of Leachman's (2005) Study. This Table represents estimated rates per cubic foot of shipment from Shanghai to the selected destinations through alternative ports of entries. This data also includes direct dray cost through ports to nearby regions (shown in Table C.1). We assumed that 90% of this cost is due to shipping of goods from Shanghai to ports of entries and the rest is for drayage, taxes, fees, etc. As shipping costs are expected to be constant regardless of destination region and mode of inland transportation, we used this assumption to come up with inland transportation costs.

Table C.1: Direct dray costs from ports to nearby regions ($ per cubic foot)

Port of Entry	Destination Region	Direct Dray Cost
Houston	Houston	1.21
LA-LB	Los Angeles	1.06
Norfolk	Norfolk	1.28
NY-NJ	New York	1.33
Oakland	Oakland	1.09
Seattle-Tacoma	Seattle-Tacoma	1.02

For example, direct dray cost is $1.06 for LA-LB Port to Los Angeles Region. 90% of this cost makes $0.954. We deduct this amount from direct rail data in order to calculate inland rail costs. The resulting data is shown in Table C.3 which represents rail transportation rates for 40-foot container (2395 cu foot).

Table C.4 and C.5 represent distance between ports, warehouses and regions (for any combination). These values were gathered directly from Google Map; and Table C.5 data were used to calculate inputs specified at Table C.6, C.7 and C.8.

Transit time calculations (Table C.6),

We have assumed that a truck can travel 16 hours every day and on average 50 miles per hour. Moreover, due to possible delays, a day or two is added to the transit time values depending on the distance between port-destination pair. An example is given below,

If distance = 853 miles

$$Transit\,Time = \frac{853}{50 \times 16} = 1.06625$$

As it is less than or equal to 1, add an additional day and round off to the nearest integer. Therefore, *Transit Time* = 2.

For a distance of 2218 miles, the first division is greater than 1 (around 2.77); therefore, consider 2 more days for possible delays and round off to the summation to the nearest integer. This gives 5 days for transit time.

The preparation of transportation costs between Ports and WHs in Table C.7 & C.8,

This is similar to the calculations for Table C.3. However, instead of using direct rail data, direct truck and trans-load truck data are used to calculate trucking cost between Ports and warehouses. Cost data between warehouses were explained in Chapter 4.

General Note: First 4 location numbers are assigned for Ports, the rest (starting from 5, up to 23) are for warehouses.

Table C.2: Assumed mean transit times for inland rail movements (days)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	TDistRail	LA-LB	NY- NJ	SA	SE-TA	Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chicago	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
1	LA-LB	100	100	100	100	4	100	100	8	6	6	6	6	6	8	8	8	8	9	9	9	9	9	9
2	NY-NJ	100	100	100	100	9	10	9	5	5	6	8	5	3	4	3	3	3	4	3	100	100	100	100
3	SA	100	100	100	100	11	11	10	7	6	4	5	3	4	1	4	5	5	3	3	3	5	4	3
4	SE-TA	100	100	100	100	100	100	4	5	8	8	10	8	6	9	8	8	9	10	9	9	9	9	9

Note 1: Some of these listed port-destination pairs do not have available railing service; in order to keep simulation logic free of errors, we assigned high-values (100) to these pairs. As a result, possibility of railing between these pairs is eliminated.

Note 2: Highlighted transit times represent values that are not supplied by the Leachman's Study. Instead of leaving them blank, we accepted transit times of the reverse directions.

Table C.3: Assumed cost values for inland rail movements of 40-foot containers ($)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Direct Rail	LA-LB	NY-NJ	SA	SE-TA	Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chicago	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
1	LA-LB	100000	100000	100000	100000	1140	100000	100000	1547	1236	1260	1332	1571	1499	1763	1619	1619	1906	1978	2026	2050	1978	2194	2314
2	NY-NJ	100000	100000	100000	100000	1564	1732	1612	1109	1253	1492	1612	1181	1109	1205	941	917	893	1109	845	100000	100000	100000	100000
3	SA	100000	100000	100000	100000	1562	1657	1490	1562	1274	1394	1394	1130	1346	915	1106	1106	1202	963	1106	1274	1226	1442	1609
4	SE-TA	100000	100000	100000	100000	100000	100000	1178	1250	1274	1394	1585	1609	1562	1849	1729	1729	1993	2112	2136	2112	2112	2232	2352

Note 3: A similar approach (as Note 1) is also followed for this matrix. Instead of value 100, we assigned 100,000.

Table C.4: Distance between ports and warehouse locations (miles)

			5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
			Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chi.	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
		City Location	Fife, WA	Tracy, CA	Ontario, CA	Rosemount, MN	Lenexa, KS	Midlothian, TX	Baytown, TX	Millington, TN	Joliet, IL	Duluth, GA	Springfield, OH	Chagrin Falls, OH	Beaver Falls, PA	Salisbury, NC	Suffolk, VA	Frederick, MD	Allentown, PA	East Brunswick, NJ	Milford, MA
1	LA-LB	W Ocean Blvd, San Pedro, CA	1131	348	51	1931	1630	1440	1580	1824	2004	2218	2214	2373	2444	2439	2693	2630	2705	2776	2977
2	NY-NJ	Corbin St, Elizabeth, NJ	2860	2887	1208	1200	1197	1563	1602	1078	801	853	570	444	395	582	415	226	84	27	210
3	SA	Main St, Savannah, GA	2952	2669	1510	1364	1063	1047	987	645	962	271	702	761	726	292	459	613	770	774	1003

Table C.5: Distance between warehouse locations (miles)

			5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	Distance		Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chi.	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
		City Location	Fife, WA	Tracy, CA	Ontario, CA	Rosemount, MN	Lenexa, KS	Midlothian, TX	Baytown, TX	Millington, TN	Joliet, IL	Duluth, GA	Springfield, OH	Chagrin Falls, OH	Beaver Falls, PA	Salisbury, NC	Suffolk, VA	Frederick, MD	Allentown, PA	East Brunswick, NJ	Milford, MA
5	Seattle-Tacoma	Fife, WA	0	791	1142	1689	1908	2232	2472	2409	2127	2709	2384	2429	2501	2873	2954	2726	2801	2870	3034
6	Oakland	Tracy, CA	791	0	361	2016	1797	1681	1896	2056	2089	2450	2386	2458	2529	2670	2937	2755	2829	2898	3062
7	Los Angeles	Ontario, CA, usa	1142	358	0	1882	1580	1396	1536	1775	1954	2169	2164	2323	2395	2390	2643	2580	2655	2726	2928
8	Minneapolis	Rosemount, MN	1690	2015	1881	0	441	1003	1243	779	435	1142	724	770	841	1157	1294	1067	1141	1210	1374
9	Kansas City	Lenexa, KS	1910	1798	1581	442	0	561	821	527	515	826	630	821	876	990	1165	1046	1121	1192	1428
10	Dallas	Midlothian, TX	2233	1678	1396	1005	561	0	256	494	930	825	1037	1211	1266	1081	1372	1358	1484	1543	1767
11	Houston	Baytown, TX	2472	1892	1536	1244	801	255	0	646	1141	800	1188	1362	1416	1055	1341	1397	1523	1582	1806
12	Memphis	Millington, TN	2414	2053	1175	813	525	494	646	0	505	459	552	726	780	623	877	873	999	1058	1282
13	Chicago	Joliet, IL	2128	2089	1955	435	515	931	1140	505	0	734	321	371	442	754	895	667	742	811	975
14	Atlanta	Duluth, GA	2714	2445	2168	1144	825	824	803	461	735	0	551	725	694	260	522	648	774	817	1057
15	Columbus	Springfield, OH	2383	2385	2164	723	628	1038	1188	553	321	552	0	196	250	440	585	421	496	567	803
16	Cleveland	Chagrin Falls, OH	2430	2458	2324	771	815	1210	1360	725	372	724	189	0	86	499	539	311	386	455	619
17	Pittsburgh	Beaver Falls, PA	2501	2528	2394	841	870	1265	1415	2394	442	693	244	85	0	466	462	234	317	388	582
18	Charlotte	Salisbury, NC	2877	2668	2390	1157	988	1081	1055	624	754	260	441	500	465	0	264	398	546	559	788
19	Norfolk	Suffolk, VA	2953	2941	1644	1293	1164	1373	1342	878	894	522	586	537	461	264	0	231	341	342	571
20	Baltimore	Frederick, MD	2724	2751	2577	1064	1041	1339	1378	854	665	629	415	308	231	399	233	0	156	203	433
21	Harrisburg	Allentown, PA	2802	2829	2654	1142	1118	1485	1524	1000	743	775	492	386	317	547	389	158	0	78	289
22	New York	East Brunswick, NJ	2869	2896	2725	1209	1189	1543	1582	1058	810	816	562	453	387	559	392	203	77	0	234
23	Boston	Milford, MA	3035	3062	2928	1375	1426	1768	1807	1283	976	1058	799	620	583	789	622	433	288	234	0

Table C.6: Assumed mean transit times for inland truck movements (days)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	TDistTruck	LA-LB	NY- NJ	SA	SE-TA	Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chicago	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
1	LA-LB	1	1	1	1	2	1	1	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	6
2	NY-NJ	1	1	1	1	6	6	4	4	2	4	4	2	2	2	2	2	1	2	2	1	1	1	1
3	SA	1	1	1	1	6	5	4	4	2	2	2	2	2	1	2	2	2	1	2	2	2	2	2
4	SE-TA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Seattle-Tacoma	2	6	6	1	1	2	2	4	4	5	5	5	5	5	5	5	5	6	6	5	6	6	6
6	Oakland	1	6	5	1	2	1	1	5	4	4	4	5	5	5	5	5	5	5	6	5	6	6	6
7	Los Angeles	1	4	4	1	2	1	1	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	6
8	Minneapolis	4	4	4	1	4	5	4	1	2	2	4	2	2	2	2	2	2	2	4	2	2	4	4
9	Kansas City	4	2	2	1	4	4	4	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	4
10	Dallas	4	4	2	1	5	4	4	2	2	1	1	2	2	2	2	4	4	2	4	4	4	4	4
11	Houston	4	4	2	1	5	4	4	4	2	1	1	2	2	2	2	4	4	2	4	4	4	4	4
12	Memphis	4	2	2	1	5	5	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	4
13	Chicago	5	2	2	1	5	5	4	2	2	2	2	2	1	2	1	1	2	2	2	2	2	2	2
14	Atlanta	5	2	1	1	5	5	5	2	2	2	2	2	2	1	2	2	2	1	2	2	2	2	2
15	Columbus	5	2	2	1	5	5	5	2	2	2	2	2	1	2	1	1	1	2	2	2	2	2	2
16	Cleveland	5	2	2	1	5	5	5	2	2	4	4	2	1	2	1	1	1	2	2	1	1	2	2
17	Pittsburgh	5	1	2	1	5	5	5	2	2	4	4	5	2	2	1	1	1	2	2	1	1	1	2
18	Charlotte	5	2	1	1	6	5	5	2	2	2	2	2	2	1	2	2	2	1	1	1	2	2	2
19	Norfolk	5	2	2	1	6	6	4	4	2	4	4	2	2	2	2	2	2	1	1	1	1	1	2
20	Baltimore	5	1	2	1	5	5	5	2	2	4	4	2	2	2	2	1	1	1	1	1	1	1	2
21	Harrisburg	5	1	2	1	6	6	5	2	2	4	4	2	2	2	2	1	1	2	1	1	1	1	1
22	New York	5	1	2	1	6	6	5	4	2	4	4	2	2	2	2	2	1	2	1	1	1	1	1
23	Boston	6	1	2	1	6	6	6	4	4	4	4	4	2	2	2	2	2	2	2	2	1	1	1

Note 4: Even if it is not logical to specify distance in between Ports (and from WHs to Ports), it was required to assign values to these cells. Red-highlighted cells represent this type of inputs.

Note 5: Seattle-Tacoma (SE-TA) Port was not used; therefore, this Port's data is not present. Minimum possible values are assigned to these values.

<u>Table C.7</u>: Assumed costs for inland 40-foot truck movements ($)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	40TruckCost	LA-LB	NY-NJ	SA	SE-TA	Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chicago	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harris.	New York	Boston
1	LA-LB	400	400	400	400	1739	637	254	2817	2409	2146	2361	2745	3104	3319	3391	3607	3679	3631	4062	3990	3942	4206	4613
2	NY-NJ	400	400	400	400	3672	3767	3624	1875	1875	2378	2450	1684	1229	1324	845	726	582	1013	606	319	151	319	366
3	SA	400	400	400	400	4028	3693	3334	2136	1657	1633	1633	1106	1514	460	1178	1250	1202	460	1178	1370	1178	1657	2041
4	SE-TA	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
5	Seattle-Tacoma	1739	3672	4028	400	400	1582	2284	3378	3816	4464	4944	4818	4254	5418	4768	4858	5002	5746	5908	5452	5602	5740	6068
6	Oakland	637	3767	3693	400	1582	400	722	4032	3594	3362	3792	4112	4178	4900	4772	4916	5058	5340	5874	5510	5658	5796	6124
7	Los Angeles	254	3624	3334	400	2284	716	400	3764	3160	2792	3072	3550	3908	4338	4328	4646	4790	4780	5286	5160	5310	5452	5856
8	Minnea.	2817	1875	2136	400	3380	4030	3762	400	882	2006	2486	1558	870	2284	1448	1540	1682	2314	2588	2134	2282	2420	2748
9	Kansas City	2409	1875	1657	400	3820	3596	3162	884	400	1122	1642	1054	1030	1652	1260	1642	1752	1980	2330	2092	2242	2384	2856
10	Dallas	2146	2378	1633	400	4466	3356	2792	2010	1122	400	512	988	1860	1650	2074	2422	2532	2162	2744	2716	2968	3086	3534
11	Houston	2361	2450	1633	400	4944	3784	3072	2488	1602	510	400	1292	2282	1600	2376	2724	2832	2110	2682	2794	3046	3164	3612
12	Memphis	2745	1684	1106	400	4828	4106	2350	1626	1050	988	1292	400	1010	918	1104	1452	1560	1246	1754	1746	1998	2116	2564
13	Chicago	3104	1229	1514	400	4256	4178	3910	870	1030	1862	2280	1010	400	1468	642	742	884	1508	1790	1334	1484	1622	1950
14	Atlanta	3319	1324	460	400	5428	4890	4336	2288	1650	1648	1606	922	1470	400	1102	1450	1388	520	1044	1296	1548	1634	2114
15	Columbus	3391	845	1178	400	4766	4770	4328	1446	1256	2076	2376	1106	642	1104	400	592	500	880	1170	842	992	1134	1606
16	Cleveland	3607	726	1250	400	4860	4916	4648	1542	1630	2420	2720	1450	744	1448	578	400	372	998	1078	622	772	910	1238
17	Pittsburgh	3679	582	1202	400	5002	5056	4788	1682	1740	2530	2830	4788	884	1386	488	370	400	932	924	468	634	776	1164
18	Charlotte	3631	1013	460	400	5754	5336	4780	2314	1976	2162	2110	1248	1508	520	882	1000	930	400	528	796	1092	1118	1576
19	Norfolk	4062	606	1178	400	5906	5882	3288	2586	2328	2746	2684	1756	1788	1044	1172	1074	922	528	400	462	682	684	1142
20	Baltimore	3990	319	1370	400	5448	5502	5154	2128	2082	2678	2756	1708	1330	1258	830	616	462	798	466	400	512	406	866
21	Harrisburg	3942	151	1178	400	5604	5658	5308	2284	2236	2970	3048	2000	1486	1550	984	772	634	1094	778	516	400	356	578
22	New York	4206	319	1657	400	5738	5792	5450	2418	2378	3086	3164	2116	1620	1632	1124	906	774	1118	784	406	354	400	468
23	Boston	4613	366	2041	400	6070	6124	5856	2750	2852	3536	3614	2566	1952	2116	1598	1240	1166	1578	1244	866	576	468	400

Note 6: Even if it is not logical to specify distance in between Ports (and from WHs to Ports), it was required to assign values to these cells. Red-highlighted cells represent this type of inputs.

Note 7: Seattle-Tacoma (SE-TA) Port was not used; therefore, this Port's data is not present. Minimum possible values are assigned to these values.

Table C.8: Assumed costs for inland 53-foot truck movements ($)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	53TruckCost	LA-LB	NY-NJ	SA	SE-TA	Seattle-Tacoma	Oakland	Los Angeles	Minnea.	Kansas City	Dallas	Houston	Memphis	Chicago	Atlanta	Columbus	Cleveland	Pittsburgh	Charlotte	Norfolk	Baltimore	Harrisburg	New York	Boston
1	LA-LB	500	500	500	500	2781	1593	406	3930	3508	3202	3432	3853	4236	4466	4542	4772	4849	4810	5270	5193	5117	5423	5845
2	NY-NJ	500	500	500	500	4416	4799	4493	3075	3075	3612	3688	2884	2386	2463	1965	1850	1697	2156	1697	1390	1237	509	1467
3	SA	500	500	500	500	4910	4833	4297	3148	2650	2612	2612	2038	2497	1348	2114	2191	2152	1386	2114	2344	2152	2650	3072
4	SE-TA	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
5	Seattle-Tacoma	2781	4416	4910	500	500	1978	2855	4223	4770	5580	6180	6023	5318	6773	5960	6073	6253	7183	7385	6815	7003	7175	7585
6	Oakland	1593	4799	4833	500	1978	500	903	5040	4493	4203	4740	5140	5223	6125	5965	6145	6323	6675	7343	6888	7073	7245	7655
7	Los Angeles	406	4493	4297	500	2855	895	500	4705	3950	3490	3840	4438	4885	5423	5410	5808	5988	5975	6608	6450	6638	6815	7320
8	Minneapolis	3930	3075	3148	500	4225	5038	4703	500	1103	2508	3108	1948	1088	2855	1810	1925	2103	2893	3235	2668	2853	3025	3435
9	Kansas City	3508	3075	2650	500	4775	4495	3953	1105	500	1403	2053	1318	1288	2065	1575	2053	2190	2475	2913	2615	2803	2980	3570
10	Dallas	3202	3612	2612	500	5583	4195	3490	2513	1403	500	640	1235	2325	2063	2593	3028	3165	2703	3430	3395	3710	3858	4418
11	Houston	3432	3688	2612	500	6180	4730	3840	3110	2003	638	500	1615	2853	2000	2970	3405	3540	2638	3353	3493	3808	3955	4515
12	Memphis	3853	2884	2038	500	6035	5133	2938	2033	1313	1235	1615	500	1263	1148	1380	1815	1950	1558	2193	2183	2498	2645	3205
13	Chicago	4236	2386	2497	500	5320	5223	4888	1088	1288	2328	2850	1263	500	1835	803	928	1105	1885	2238	1668	1855	2028	2438
14	Atlanta	4466	2463	1348	500	6785	6113	5420	2860	2063	2060	2008	1153	1838	500	1378	1813	1735	650	1305	1620	1935	2043	2643
15	Columbus	4542	1965	2114	500	5958	5963	5410	1808	1570	2595	2970	1383	803	1380	500	790	625	1100	1463	1053	1240	1418	2008
16	Cleveland	4772	1850	2191	500	6075	6145	5810	1928	2038	3025	3400	1813	930	1810	773	500	515	1248	1348	778	965	1138	1548
17	Pittsburgh	4849	1697	2152	500	6253	6320	5985	2103	2175	3163	3538	5985	1105	1733	610	513	500	1165	1155	585	793	970	1455
18	Charlotte	4810	2156	1386	500	7193	6670	5975	2893	2470	2703	2638	1560	1885	650	1103	1250	1163	500	660	995	1365	1398	1970
19	Norfolk	5270	1697	2114	500	7383	7353	4110	3233	2910	3433	3355	2195	2235	1305	1465	1343	1153	660	500	578	853	855	1428
20	Baltimore	5193	1390	2344	500	6810	6878	6443	2660	2603	3348	3445	2135	1663	1573	1038	770	578	998	583	500	690	508	1083
21	Harrisburg	5117	1237	2152	500	7005	7073	6635	2855	2795	3713	3810	2500	1858	1938	1230	965	793	1368	973	695	500	495	723
22	New York	5423	509	2650	500	7173	7240	6813	3023	2973	3858	3955	2645	2025	2040	1405	1133	968	1398	980	508	493	500	585
23	Boston	5845	1467	3072	500	7588	7655	7320	3438	3565	4420	4518	3208	2440	2645	1998	1550	1458	1973	1555	1083	720	585	500

Note 8: Even if it is not logical to specify distance in between Ports (and from WHs to Ports), it was required to assign values to these cells. Red-highlighted cells represent this type of inputs.

Note 9: Seattle-Tacoma (SE-TA) Port was not used; therefore, this Port's data is not present. Minimum possible values are assigned to these values.

Appendix D

Below, we provide detailed information about the logistics template that we have developed for Arena.

General Information and Assumptions:

- Each node is represented by a location number. This number should be set via node's interface and it should be unique for each port, IWH, RWH and region. Generally, this input is being used as an index for certain variables.
- Rail service is not implemented for IWH-RWH and RWH-Region pairs.
- Some variables should be set through Variables Module at Basic Process Template of Arena. They can be classified into two groups:
    1. General cost and duration variables.

       These variables are required for simulation purposes. They define general cost and duration parameters between locations.

  TDistOrigin(i, j): duration for shipments from Product Origin location i to Port at j.

  TDistRail(i, j): duration for rail shipments from Port location i to IWH at j.

  TDistTruck(i, j): duration for truck shipments from location i to j.

  ShippingOriginCost(i, j): cost of shipments from Product Origin location i to Port at j.

  RailCost(i, j): cost of rail shipments from Port location i to IWH at j.

  40TruckCost(i, j): cost for 40ft container shipments from location i to j.

  53TruckCost(i, j): cost for 53ft container shipments from location i to j.

Note: TDistOrigin and ShippingOriginCost variables define duration and cost of shipments independent of the transportation method (trucking, rail, ocean). As a result, these variables should be updated according to the transportation method defined at the Product Origin.

2. Variables required for optimization purposes.

   These variables are used to control variables of the OptQuest model. There is no need to input these variables unless we seek to optimize a logistics network.

LocVar(i, 5): location variables -location number, facility value, delay per order, ordering and handling costs-for international and regional warehouses.

LN_I_k: location number for k^{th} IWH.

LN_R_k: location number for k^{th} RWH.

- Liability of products is transferred to the importer company when goods are received at the Port of Entry.
- Every node in the logistics network is operational non-stop throughout the year.

DOE Control

This module has been added to the template for the purpose of experimental design. It facilitates data manipulation between simulation runs.

- It controls certain cost and time inputs of a model.

- For example, if the shipping cost is $1000 for an origin-destination pair and the cost multiplier for ocean transportation set to "1.5" through this module, then the shipping cost will be taken as $1500 for that simulation run.

- Entered values should be non-zero real numbers. This is crucial especially for the transportation time multipliers.

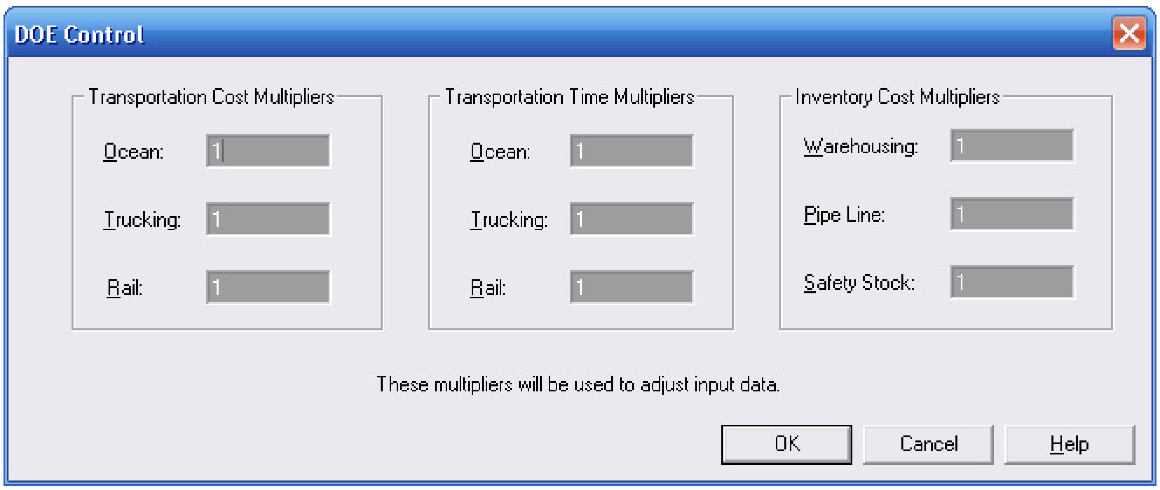


Figure D.1: Dialog box of DOE Control module

Seasonality

Seasonality effects on sales volume should also be considered in logistics networks. For this reason, seasonality module has been implemented into the template. Generally, it is used for creating demand variability between consequent seasons.

- Although this module was built to handle different seasonality inputs; for the time being, it supports only bi-periodic seasonal input.

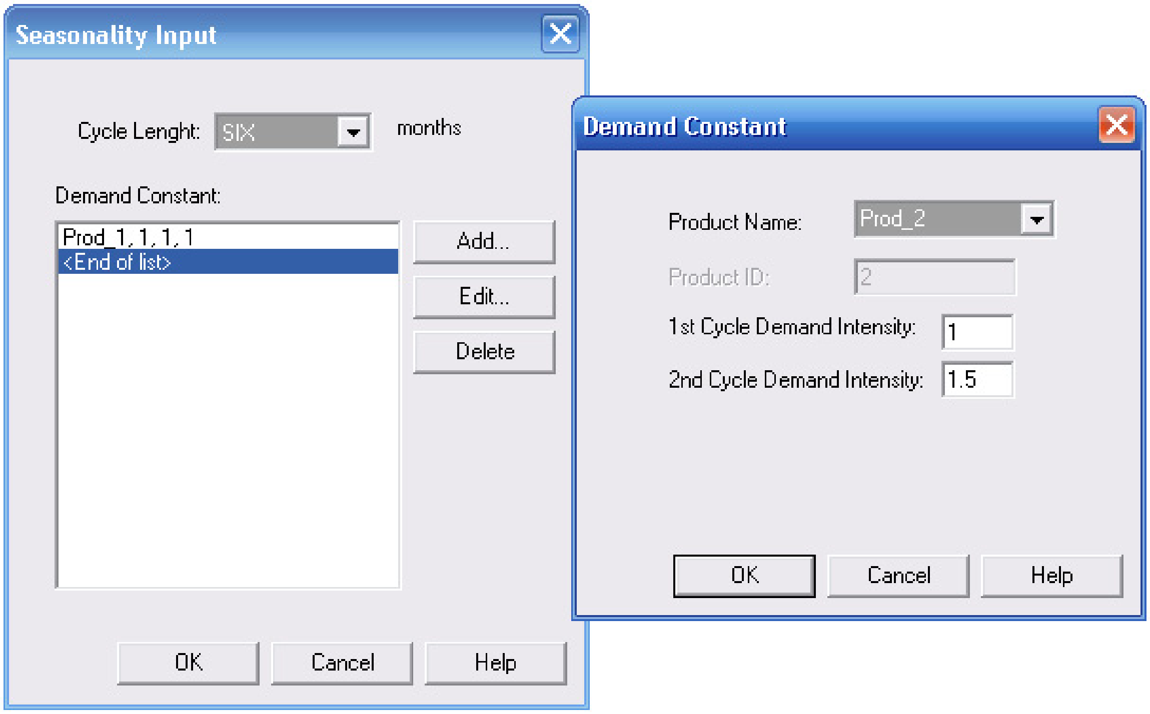
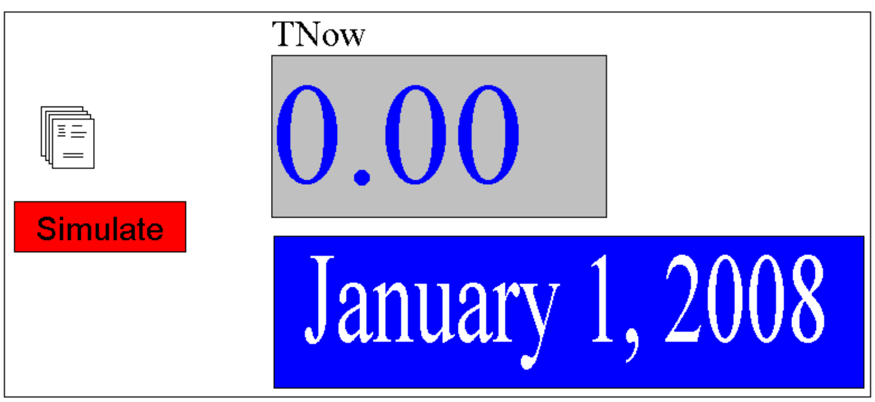


Figure D.2: Dialog box of Seasonality module

- If Seasonality Module is going to be used, the simulation start date and time should be set to January 1st (any year, preferably 2008) at 12:00 am.
- These cycles are based on calendar year. Therefore, the first cycle of the year starts on January 1st and the last cycle ends on December 31st. For the implemented six-month cycle, 1st cycle starts on January 1st and 2nd cycle starts on July 1st. These cycles takes place one after the other throughout the simulation run.
- Demand intensities entered are used to adjust demand quantities for each region. This logic is quiet similar to the DOE control.
- In order to prevent uncontrollable inventory fluctuations at warehouses, keep variability of the demand intensity within 0 to 3.

- This module controls certain replication parameters of the simulation run such as warm-up period, length and number of replications.
- "Simulation cost calculation" input is being used to calculate a desired cost output value to the output file. For example:
  - Origin 1_OveallCost (1) + Port 1_OverallCost + IWH 1_OverallCost + RWH 1_OverallCost
  - This part should not be left blank.
- The date variable window next to Simulate object should be syncronized with the simulation start date and time.
- Other inputs (project title, analyst, date) are reference information that will be shown in the output file.



<u>Figure D.3</u>: Seasonality module on canvas

(1) There is a typo in the model regarding this variable. It was supposed to be "OverallCost".

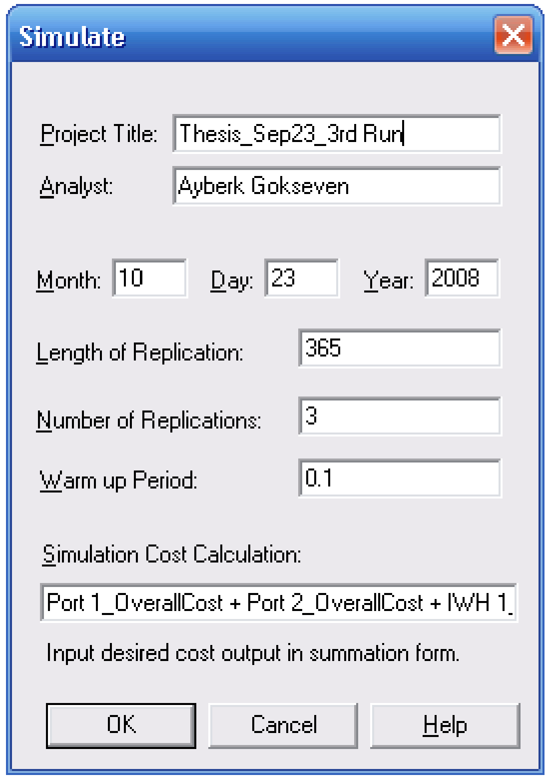


Figure D.4: Dialog box of Simulate module

Product Input

This module is for inputting pipeline, safety-stock and lost sales costs for products.

- The template is limited to 50 products.
- The module is also responsible for inputting container capacities in terms of twenty-equivalent units (TEU). Three different container capacities are considered; and they are hardcoded into the template:

20 ft standard volume container = 1163 cu ft = 1 TEU

40 ft standard volume container = 2395 cu ft = 1 FEU

53 ft standard volume container = 3830 cu ft

Therefore,

40ft = 2.05 TEUs, assume **40ft container = 2 TEUs**

53ft = 3.29 TEUs, assume **53ft container = 3 TEUs**

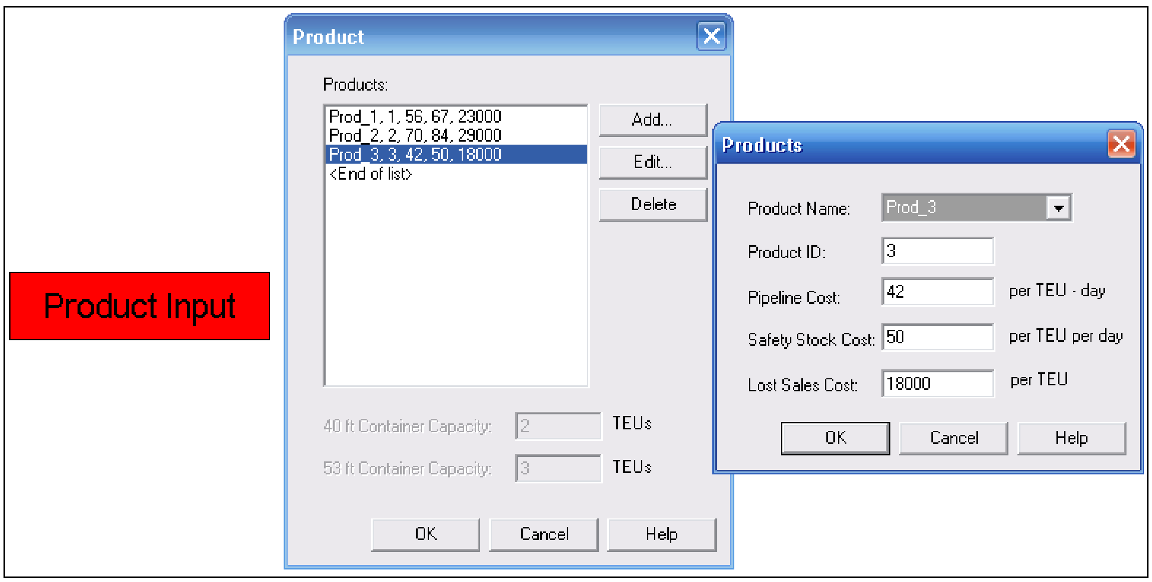


Figure D.5: Dialog box of Product Input module

Region

Region modules represent the customer base of the company. According to the implemented logic in the template, a given market can be represented with multiple regions which is quiet similar to the clustering methodology.

- Every Region is associated with a regional warehouse and only this warehouse can supply that region. This connection is set via Region's dialog box.
- Demand inputs are based on normal distributions. If the generated value is negative, then that number will be replaced by zero (this was set as a precaution to generating negative values).
- Orders are generated on daily basis and sent to the assigned RWH.
- If an order is partially satisfied, the unsatisfied amount is accepted as lost sales.
- There are multiple variable windows associated with this module. These windows are kept in order to follow up the simulation run beneath the user view. Mean and standard deviation of the demand distributions are shown by "Mean i" and "Std i" windows; last ordered quantities are displayed by "Order i" (only the first three products' information are shown, the rest are being kept internally). "DestinationStation" and "LocNo" show the station number of the assigned RWH and the location number of the region, respectively.

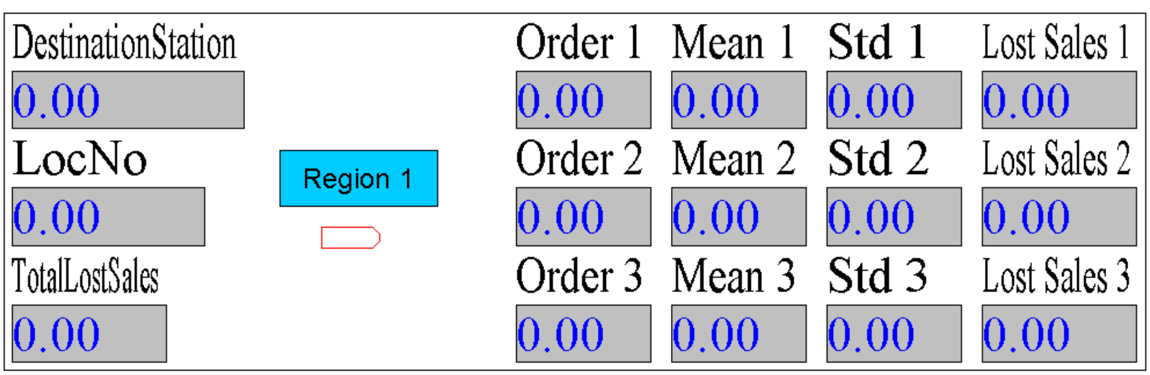


Figure D.6: Region module on canvas

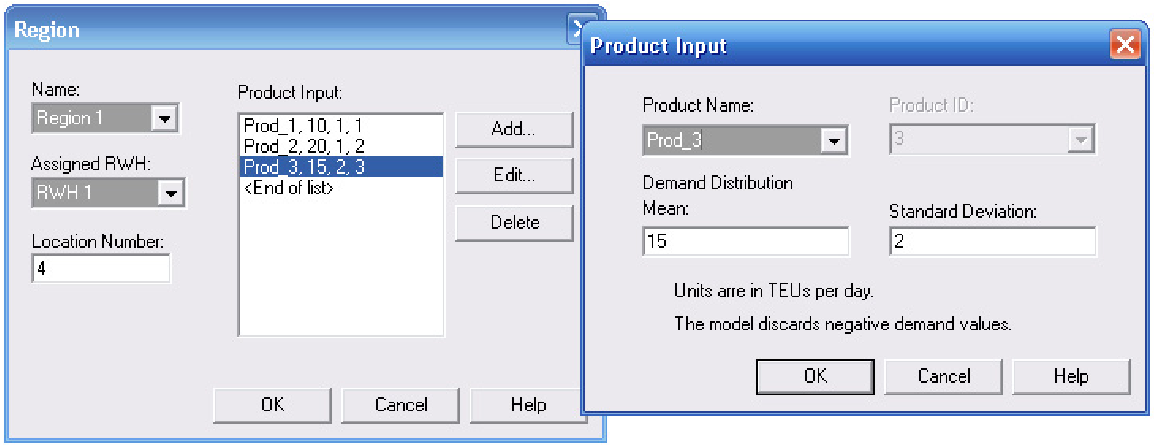


Figure D.7: Dialog box of Region module

Regional WH

- Regional Warehouses reside between International Warehouses and Regions.
- A RWH can only be supplied from one IWH.
- If associated IWH cannot satisfy the overall order, then inventory positions for those products will be adjusted accordingly.
- Multiple parameters can be entered by using RWH interface, shown in Figure D.9. Most of them are all self explanatory except "inventory control" input.
    - There are three different options (manual input, Type-1 and Type 2 calculations) to set inventory control parameters to the model. According to the selected option, the interface asks for alternative inputs that are shown in Figure D.9 and D.10. Check Section 3.1.1 for the equations of Type-1 and Type-2 calculations.

  - When seasonality effects on demand are allowed, different inventory control parameters should be set for each season. This is important for adequately supplying demand of the lower echelon. This variability in the model can be provided by either Type-1 or Type-2 option. Simply put, if one of these options are selected, inventory parameters of the RWH are updated based on the estimated demand from the lower echelon prior to the beginning of each cycle (25th day of the last month of the previous cycle).
- When an order arrives:
  - Demand is supplied depending on the available stock.
  - If an order is partially satisfied, the unsatisfied quantity is accepted as lost sales. This might be converted into dollar value if lost sales costs are set via product input module.
  - Demand quantities are based on TEUs; the whole supply is consolidated into 40-foot and/or 53-foot containers and sent to the destination. The priority is sending goods with 53-foot containers. 40-foot containers are used if remaining supply cannot fill more than 2/3 of the 53-foot container.
  - The whole supply is assumed to be sent by a single convoy entity which is (possibly) composed of multiple trucks.
- There are some important variable windows next to RWH object:
  - Order up to level (OuL i), re-order level (RoL i), pipeline cost (PL Cost i), safety-stock cost (SS Cost i), supply quantity of the last order (Supply i), estimated demand of lower exhelon (Est DMND i) and standard deviation of demand (Std Dev i).

- Overall Cost includes facility, handling, ordering, trucking, pipeline (TotPipeCost), safety-stock (TotSSCost) and lost sales costs.

- Pipeline cost is referring to the transit inventory cost in between IWH and RWH.

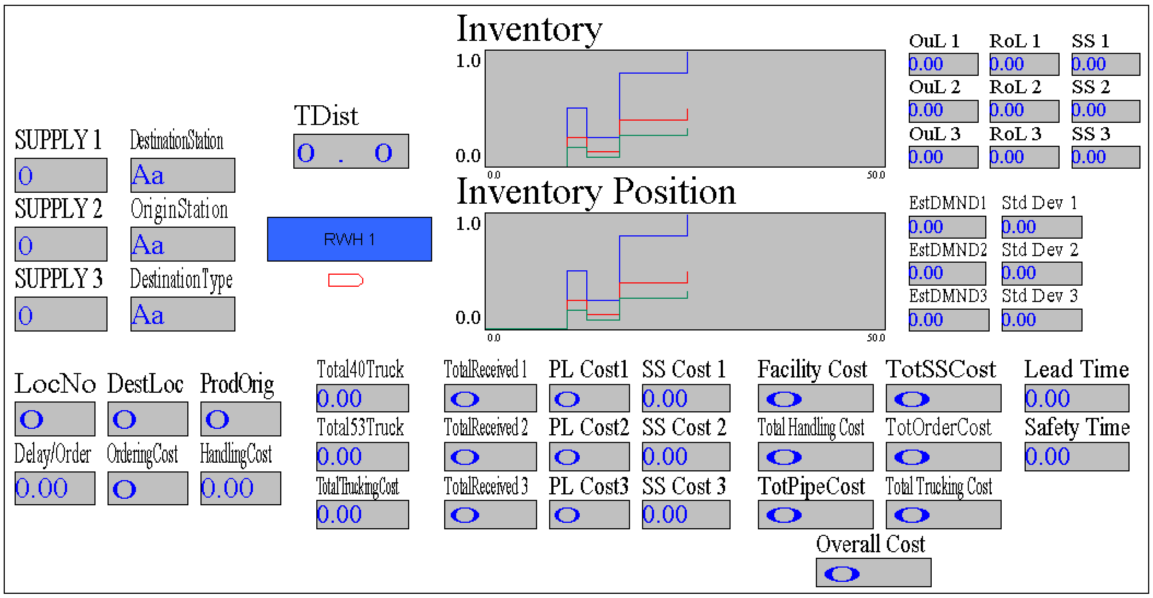


Figure D.8: RWH module on canvas

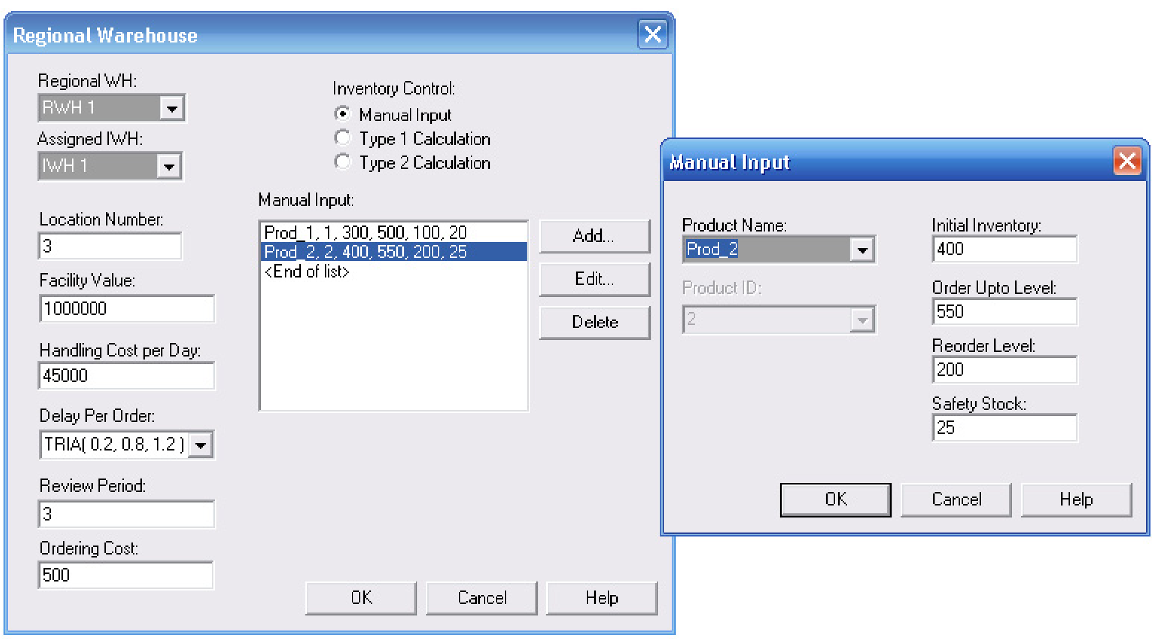


Figure D.9: Dialog box of RWH module with manual input option

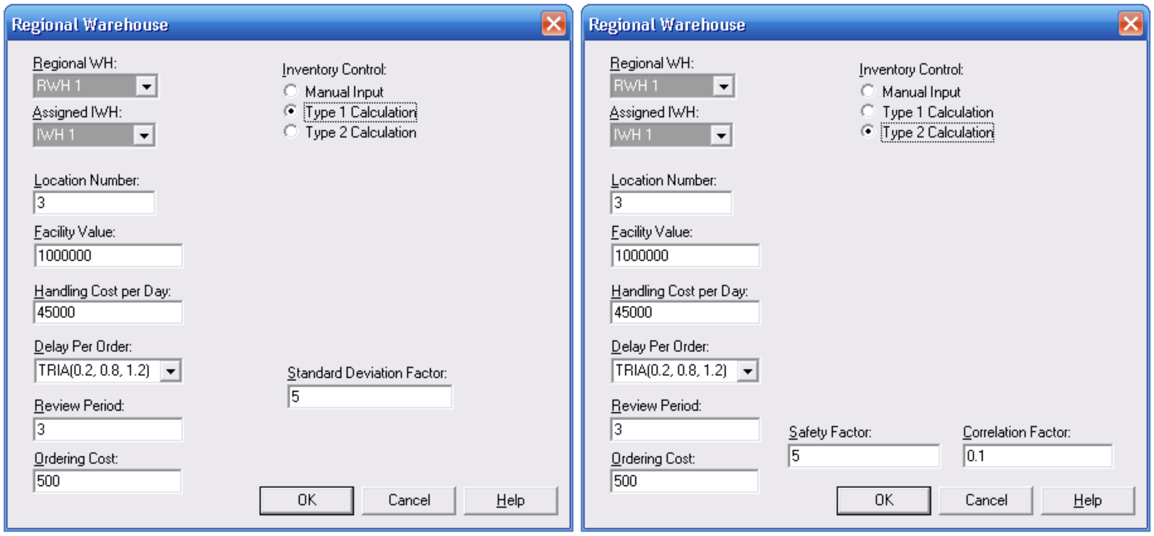


Figure D.10: Dialog boxes of RWH module with Type-1 and Type-2 options

International WH

- International warehouses reside between Ports and RWHs.
- IWH module is quiet similar to RWH's, except its ordering mechanism.
    - IWHs send their orders to Product Origin nodes and receive supply through Ports. Each IWH can be supplied through one Origin-Port pair.
- Pipeline cost is referring to the transit inventory cost in between Port and IWH. This is due to the assumption about the transfer of liability of products at the Port of Entry.
- There is no lost sales cost associated with IWH module. If RWH's demand is unable to be satisfied (or it can be partially satisfied), a notification will be sent to the RWH. This notification will adjust inventory position parameters. It is

responsible for lowering the inventory parameter by the magnitude of unsatisfied order quantity. With the updated inventory parameters, RWH will check its inventory in the next review period and place order for required products.

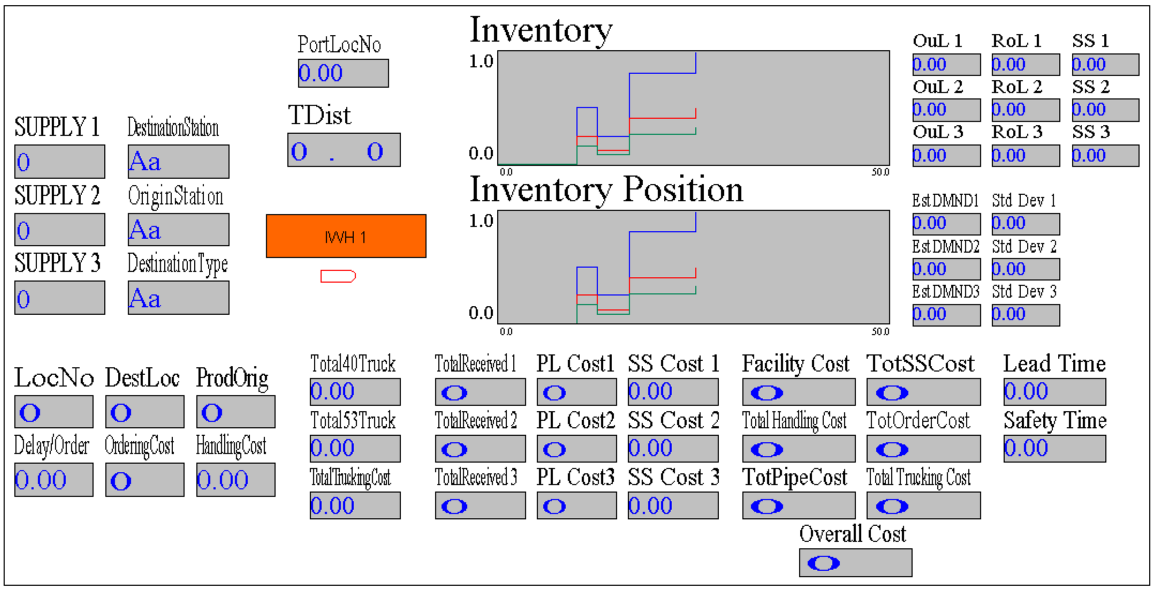


Figure D.11: IWH module on canvas

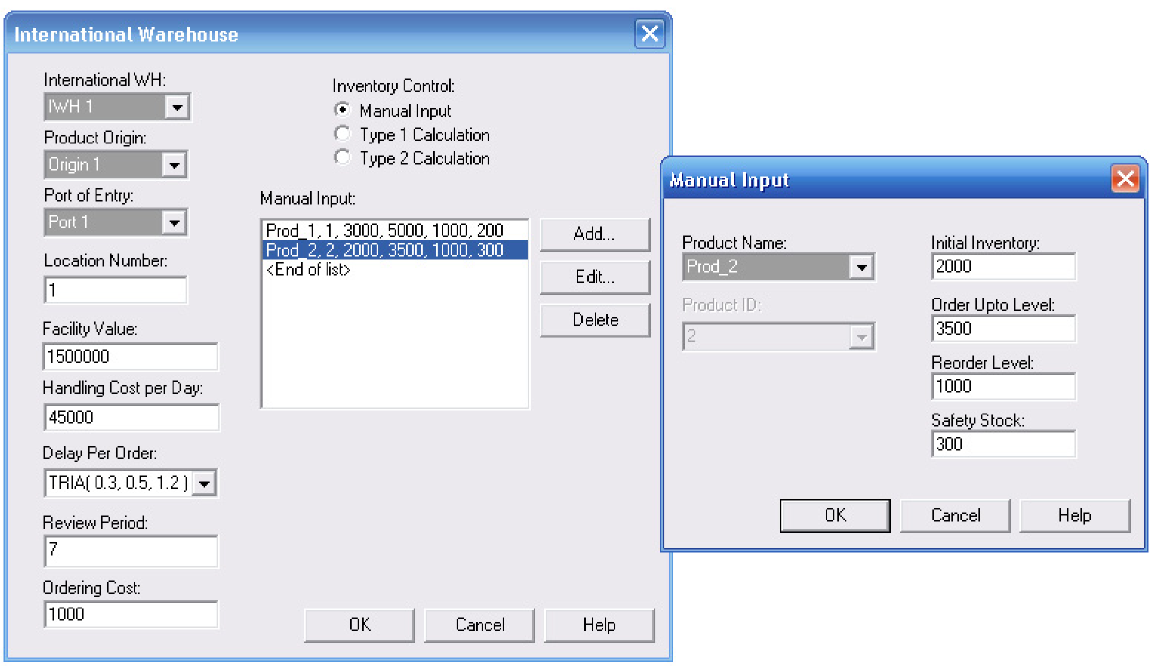


Figure D.12: Dialog box of IWH module with manual input option

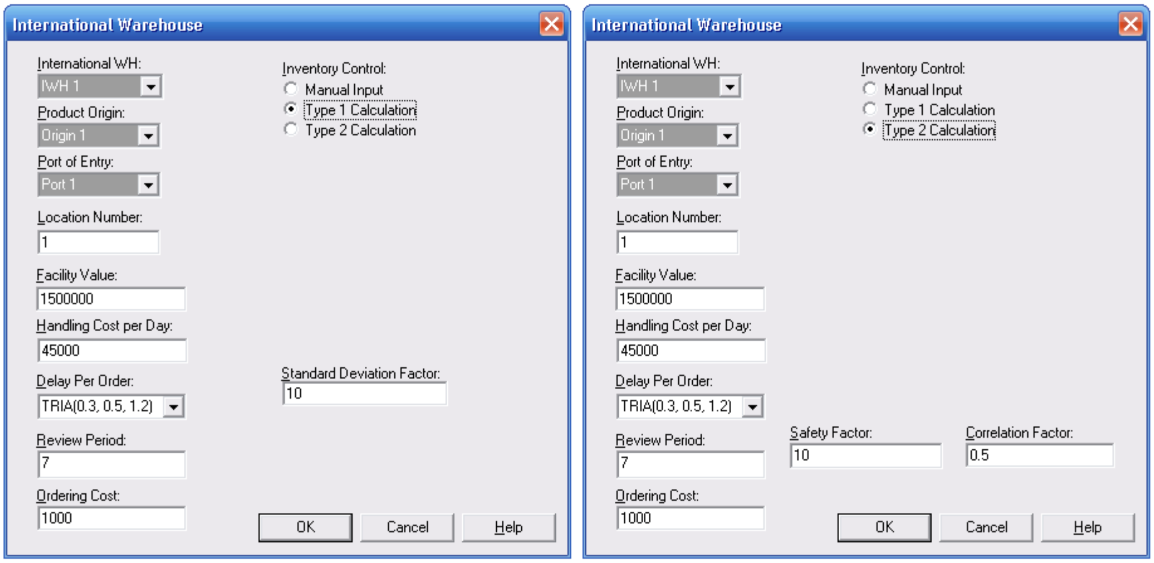


Figure D.13: Dialog box of IWH module with Type-1 and Type-2 options

Port

- Ports reside between Product Origin and IWHs. They are responsible for debarkation of containers coming from Product Origin.
- Two transportation methods -trucking and rail- have been implemented in this module. The modeler is allowed to choose either one of these methods which can be set by three different options.
    - "Trucking" option is accepted as the basic transportation method. When this option is selected, all duration and cost inputs for 40-foot and 53-foot trucking should be entered to the model.
    - "Rail" option is set as an alternate to trucking. Even though only rail transportation is selected for a port, in reality this service may not be

available for some Port-IWH pairs. For this reason, rail transportation is relaxed by allowing transportation of goods by trucking whenever rail transportation is not defined for a Port-IWH pair.

- "Truck or rail" option allows the model to choose between trucking or rail transportation depending on the duration of transportation between each Port-IWH pair.

- In the template, there is no scheduling for rail transportation. Variability for train arrivals might be set together with other delays at the port through "delay per order" and "std dev of lead time".
- Cross-docking to 40-foot containers is assumed to be done at every Port regardless of the transportation method; however, cross-docking to 53-ft containers is left as an option for the modeler and it is valid with only "trucking" option. Thus, for "rail" option, only 40-foot containers will be used to transport merchandise to IWHs; this is independent of the available transportation method.
- Overall cost is equal to total cost per order (TotalCost/Order), total container fee (Total Cont Fee) and total transportation cost.

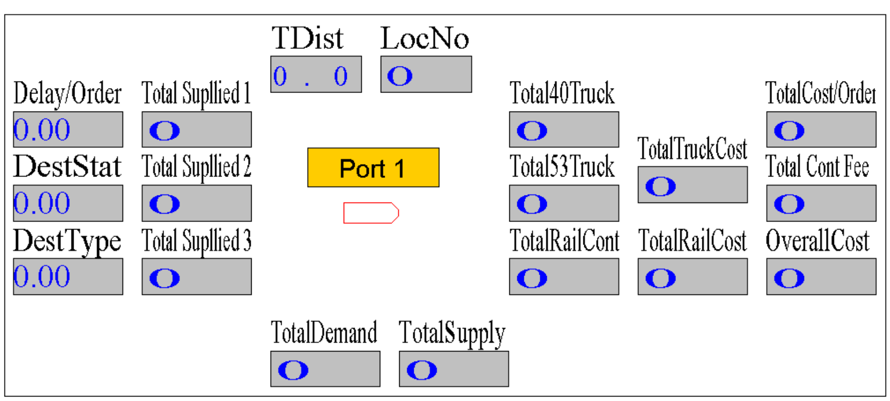


Figure D.14: Port module on canvas

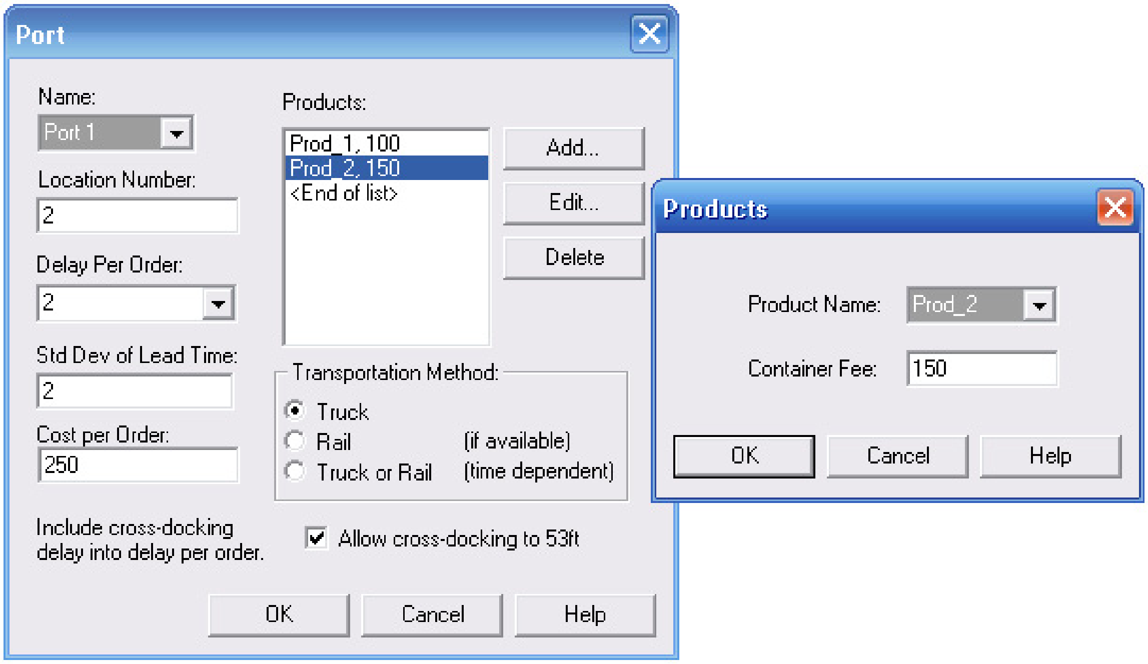


Figure D.15: Dialog box of Port module

Product Origin

In order to simulate a source for products, we introduced Product Origin module into the template. This module is responsible for supplying overall demand in the model.

- Origin modules are accepted as infinite source of product. Therefore, they have the capability of supplying any amount without backordering or losing sales. A supporting assumption for this reasoning is the concept of blanket orders. In other words, the importer company is assumed to be making agreements with its vendors to secure forecasted amount of merchandise.
- The whole supply is assumed to be sent by either a single entity -a ship or a train- or a convoy entity, which is composed of multiple trucks.

- 40-foot containers are used for transportation to Port of Entries.
- Overall Cost is based on total cost per order (Total Cost/Order), total container fee (Total Cont Fee) and total shipping cost.

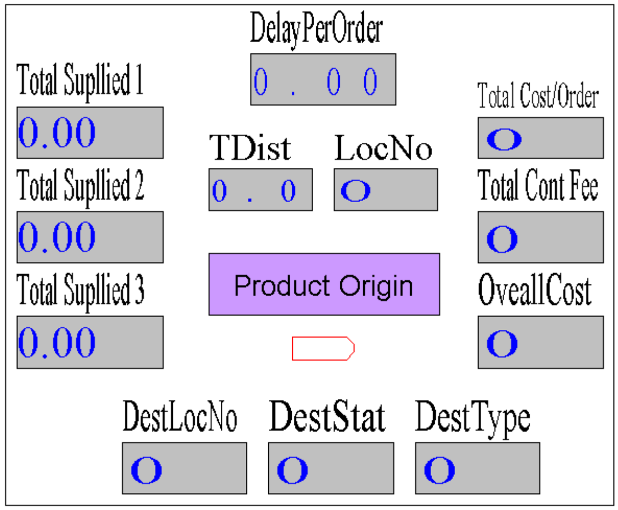


Figure D.16: Product Origin module on canvas

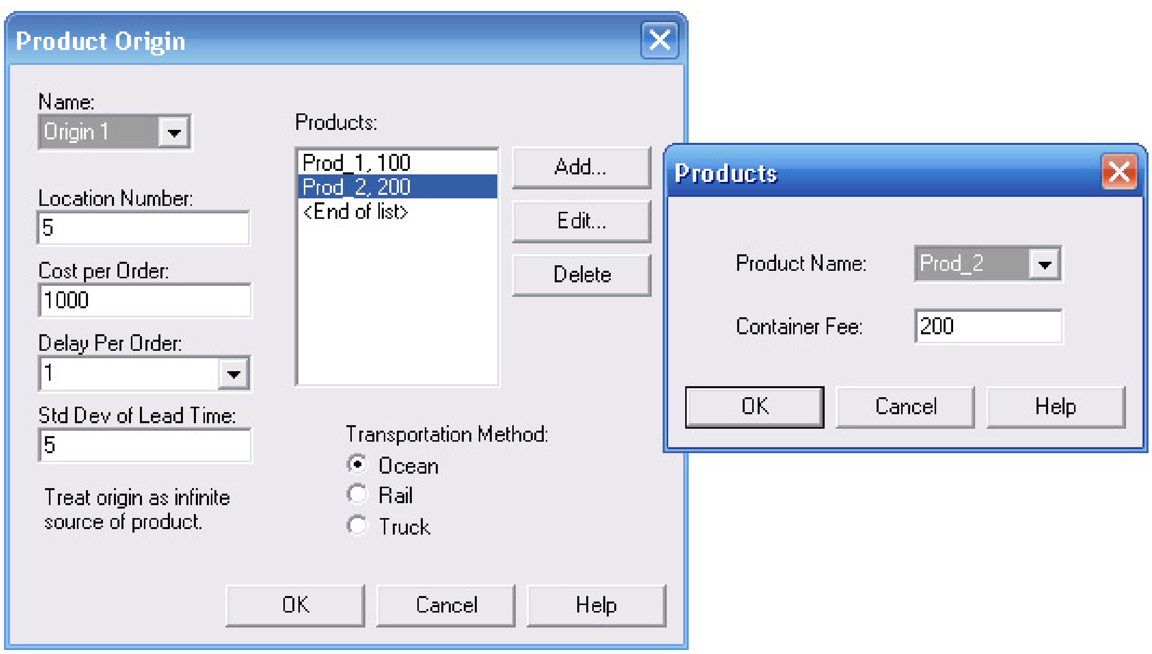


Figure D.17: Dialog box of Product Origin module

Appendix E

Model 4 Outputs

In this section, we introduce a summarized version of the output values of our models; and as an example, we have picked Model 4's simulation-optimization outputs. Figure E.1 and E.2 represent screenshots from OptQuest software. Our intention to show this figure was to give an idea about the optimization procedure. According to these figures, the optimization problem has found its optimal answer at the 407th simulation. Nonetheless, we kept this optimization model running for another 30,000 combinations of different logistic network scenarios (Generally, we kept every model running not less than 15,000 additional combinations from the last found best solution).

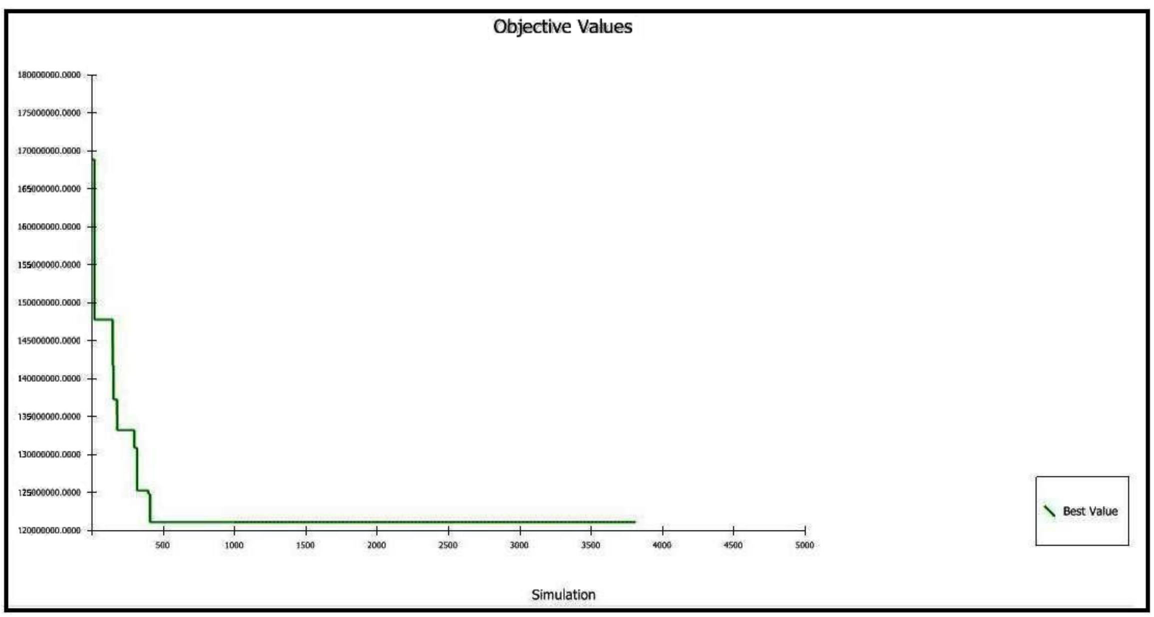
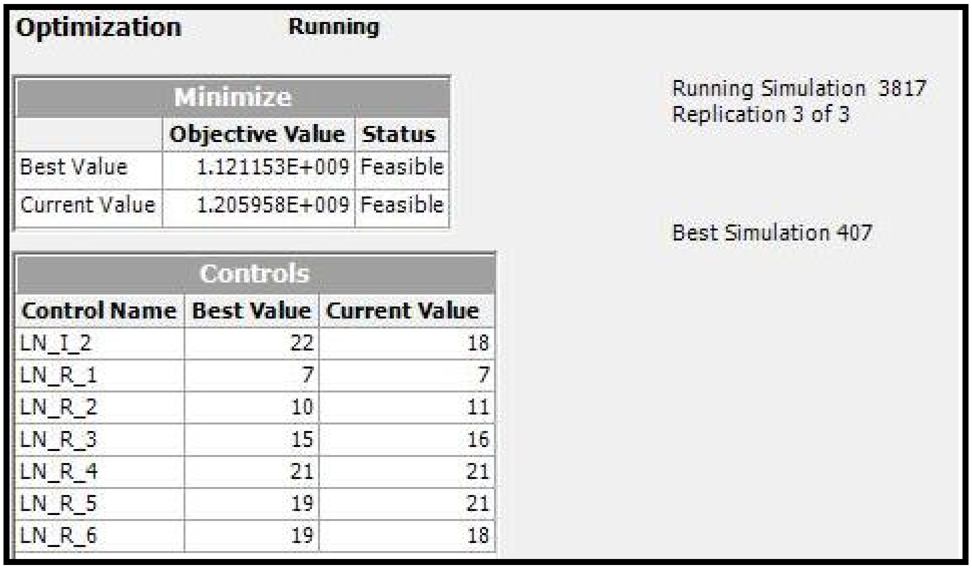


Figure E.1: OptQuest chart representing expected cost values



Optimization Running

Minimize		
	Objective Value	Status
Best Value	1.121153E+009	Feasible
Current Value	1.205958E+009	Feasible

Running Simulation 3817
Replication 3 of 3

Best Simulation 407

Control Name	Best Value	Current Value
LN_I_2	22	18
LN_R_1	7	7
LN_R_2	10	11
LN_R_3	15	16
LN_R_4	21	21
LN_R_5	19	21
LN_R_6	19	18

Figure E.2: Numerical output of the optimization model during the iterations

- “LN_I_x” stands for the location of IWH x.
- “LN_R_y” stands for the location of RWH y.
- Units of demand, inventory parameters and lost sales are in TEUs.
- Units of cost values are in dollars.
- Satisfaction levels are between 0 and 1.
- Units of time parameters are in days.
- Abbreviations:
  - “Inv” stands for on-hand inventory level,
  - “SS” stands for safety-stock level.

Below, we represent the outputs of simulation model for the optimum (warehousing location) solution achieved from the OptQuest.

Table E.1: Cost values from Origin and Port nodes ($)

	Value
Origin 1_Overall Cost	230,499,500
Port 1_Overall Cost	12,627,378
Port 2_Overall Cost	23,726,141

Table E.2: Outputs of International Warehouses

	Average	**Half Width**	**Min**	**Max**	**Obs.**
IWH 1 Outbound Order Satisfaction	1				
IWH 1 Overall Response Time	19.004	(Insuf)	19.004	19.005	101
IWH 1 Port Response Time	4.002	(Insuf)	4.002	4.002	101
IWH 1_Inv(01)	815.54	(Corr)	693	1298	830
IWH 1_Inv(02)	411.2	(Corr)	335	658	420
IWH 1_Inv(03)	1225.9	(Corr)	1068	1942	1243
IWH 1_OrderUptoLevel(01)	1309	(Insuf)	1309	1309	1309
IWH 1_OrderUptoLevel(02)	663	(Insuf)	663	663	663
IWH 1_OrderUptoLevel(03)	1958	(Insuf)	1958	1958	1958
IWH 1_ReorderLevel(01)	1287	(Insuf)	1287	1287	1287
IWH 1_ReorderLevel(02)	652	(Insuf)	652	652	652
IWH 1_ReorderLevel(03)	1925	(Insuf)	1925	1925	1925
IWH 1_SS(01)	1191	(Insuf)	1191	1191	1191
IWH 1_SS(02)	604	(Insuf)	604	604	604
IWH 1_SS(03)	1781	(Insuf)	1781	1781	1781
IWH 1_Total Ordering Cost	31,200				
IWH 1_Total Handling Cost	34,894,000				
IWH 1_Total Safety Stock Cost	160,295,590				
IWH 1_Total Pipeline Cost	9,603,535				
IWH 1_Total Trucking Cost	30,008,264				
IWH 1_Overall Cost	234,832,589				
IWH 2 Outbound Order Satisfaction	1				
IWH 2 Overall Response Time	31.004	(Insuf)	31.004	31.005	99
IWH 2 Port Response Time	4.002	(Insuf)	4.002	4.002	99
IWH 2_Inv(01)	876.45	(Corr)	680	1989	815
IWH 2_Inv(02)	479.63	(Corr)	363	1099	465
IWH 2_Inv(03)	1313.7	(Corr)	1073	2944	1211
IWH 2_OrderUptoLevel(01)	2005	(Insuf)	2005	2005	2005

IWH 2_OrderUptoLevel(02)	1108	(Insuf)	1108	1108	1108
IWH 2_OrderUptoLevel(03)	2968	(Insuf)	2968	2968	2968
IWH 2_ReorderLevel(01)	1972	(Insuf)	1972	1972	1972
IWH 2_ReorderLevel(02)	1090	(Insuf)	1090	1090	1090
IWH 2_ReorderLevel(03)	2919	(Insuf)	2919	2919	2919
IWH 2_SS(01)	1788	(Insuf)	1788	1788	1788
IWH 2_SS(02)	989	(Insuf)	989	989	989
IWH 2_SS(03)	2646	(Insuf)	2646	2646	2646
IWH 2_Total Ordering Cost	31,200				
IWH 2_Total Handling Cost	36,427,000				
IWH 2_Total Safety Stock Cost	244,675,560				
IWH 2_Total Pipeline Cost	14,491,082				
IWH 2_Total Trucking Cost	24,206,849				
IWH 2_Overall Cost	319,831,691				

Table E.3: Outputs of Regional Warehouses

	Average	**Half Width**	**Min**	**Max**	**Obs.**
RWH 1 IWH Response Time	1.313	0.04676	0.31376	2.738	364
RWH 1 Inbound Order Satisfaction	1				
RWH 1 Outbound Order Satisfaction	0.99863				
RWH 1_Inv(01)	35.283	0.66832	0	63	42
RWH 1_Inv(02)	20.929	(Corr)	0	35	24
RWH 1_Inv(03)	51.101	1.0086	0	93	56
RWH 1_OrderUptoLevel(01)	63	(Insuf)	63	63	63
RWH 1_OrderUptoLevel(02)	35	(Insuf)	35	35	35
RWH 1_OrderUptoLevel(03)	93	(Insuf)	93	93	93
RWH 1_ReorderLevel(01)	51	(Insuf)	51	51	51
RWH 1_ReorderLevel(02)	29	(Insuf)	29	29	29
RWH 1_ReorderLevel(03)	75	(Insuf)	75	75	75
RWH 1_SS(01)	38	(Insuf)	38	38	38
RWH 1_SS(02)	22	(Insuf)	22	22	22
RWH 1_SS(03)	56	(Insuf)	56	56	56
RWH 1_Total Lost Sales Cost	99,000				
RWH 1_Total Ordering Cost	109,200				
RWH 1_Total Handling Cost	34,894,000				
RWH 1_Total Safety Stock Cost	5,251,620				
RWH 1_Total Pipeline Cost	1,771,993				

RWH 1_Total Trucking Cost	9,584,823				
RWH 1_Overall Cost	51,710,636				
RWH 2 IWH Response Time	4.3636	0.05121	2.9473	5.9996	362
RWH 2 Inbound Order Satisfaction	1				
RWH 2 Outbound Order Satisfaction	0.97089				
RWH 2_Inv(01)	22.066	1.0439	0	72	19
RWH 2_Inv(02)	21.472	1.0108	0	48	19
RWH 2_Inv(03)	27.131	1.2372	0	100	14
RWH 2_OrderUptoLevel(01)	77	(Insuf)	77	77	77
RWH 2_OrderUptoLevel(02)	50	(Insuf)	50	50	50
RWH 2_OrderUptoLevel(03)	107	(Insuf)	107	107	107
RWH 2_ReorderLevel(01)	67	(Insuf)	67	67	67
RWH 2_ReorderLevel(02)	45	(Insuf)	45	45	45
RWH 2_ReorderLevel(03)	92	(Insuf)	92	92	92
RWH 2_SS(01)	46	(Insuf)	46	46	46
RWH 2_SS(02)	34	(Insuf)	34	34	34
RWH 2_SS(03)	60	(Insuf)	60	60	60
RWH 2_Total Lost Sales Cost	4,991,000				
RWH 2_Total Ordering Cost	109,200				
RWH 2_Total Handling Cost	24,455,000				
RWH 2_Total Safety Stock Cost	6,524,740				
RWH 2_Total Pipeline Cost	4,872,860				
RWH 2_Total Trucking Cost	8,947,717				
RWH 2_Overall Cost	49,900,517				
RWH 3 IWH Response Time	2.3864	0.0502	0.63822	3.8527	363
RWH 3 Inbound Order Satisfaction	1				
RWH 3 Outbound Order Satisfaction	0.98539				
RWH 3_Inv(01)	20.216	0.63523	0	47	15
RWH 3_Inv(02)	16.404	0.67873	0	32	13
RWH 3_Inv(03)	28.021	0.81916	0	68	18
RWH 3_OrderUptoLevel(01)	51	(Insuf)	51	51	51
RWH 3_OrderUptoLevel(02)	34	(Insuf)	34	34	34
RWH 3_OrderUptoLevel(03)	75	(Insuf)	75	75	75
RWH 3_ReorderLevel(01)	42	(Insuf)	42	42	42
RWH 3_ReorderLevel(02)	29	(Insuf)	29	29	29
RWH 3_ReorderLevel(03)	61	(Insuf)	61	61	61
RWH 3_SS(01)	32	(Insuf)	32	32	32
RWH 3_SS(02)	23	(Insuf)	23	23	23
RWH 3_SS(03)	45	(Insuf)	45	45	45

RWH 3_Total Lost Sales Cost	2,102,000				
RWH 3_Total Ordering Cost	109,200				
RWH 3_Total Handling Cost	27,010,000				
RWH 3_Total Safety Stock Cost	4,617,980				
RWH 3_Total Pipeline Cost	2,518,833				
RWH 3_Total Trucking Cost	5,467,094				
RWH 3_Overall Cost	41,825,107				
RWH 4 IWH Response Time	1.4574	0.04734	0.41139	2.7371	363
RWH 4 Inbound Order Satisfaction	1				
RWH 4 Outbound Order Satisfaction	0.99521				
RWH 4_Inv(01)	23.607	0.54305	0	40	11
RWH 4_Inv(02)	14.363	0.36355	0	24	10
RWH 4_Inv(03)	34.548	0.89654	0	62	13
RWH 4_OrderUptoLevel(01)	44	(Insuf)	44	44	44
RWH 4_OrderUptoLevel(02)	25	(Insuf)	25	25	25
RWH 4_OrderUptoLevel(03)	68	(Insuf)	68	68	68
RWH 4_ReorderLevel(01)	36	(Insuf)	36	36	36
RWH 4_ReorderLevel(02)	21	(Insuf)	21	21	21
RWH 4_ReorderLevel(03)	55	(Insuf)	55	55	55
RWH 4_SS(01)	27	(Insuf)	27	27	27
RWH 4_SS(02)	16	(Insuf)	16	16	16
RWH 4_SS(03)	41	(Insuf)	41	41	41
RWH 4_Total Lost Sales Cost	312,000				
RWH 4_Total Ordering Cost	109,200				
RWH 4_Total Handling Cost	30,660,000				
RWH 4_Total Safety Stock Cost	3,798,190				
RWH 4_Total Pipeline Cost	1,354,072				
RWH 4_Total Trucking Cost	3,575,535				
RWH 4_Overall Cost	39,808,997				
RWH 5 IWH Response Time	1.4321	0.06233	0.42343	2.6723	364
RWH 5 Inbound Order Satisfaction	1				
RWH 5 Outbound Order Satisfaction	0.99966				
RWH 5_Inv(01)	21.404	0.58104	0	36	21
RWH 5_Inv(02)	17.807	0.49281	0	28	19
RWH 5_Inv(03)	26.155	0.63997	3	45	32
RWH 5_OrderUptoLevel(01)	36	(Insuf)	36	36	36
RWH 5_OrderUptoLevel(02)	28	(Insuf)	28	28	28
RWH 5_OrderUptoLevel(03)	45	(Insuf)	45	45	45
RWH 5_ReorderLevel(01)	30	(Insuf)	30	30	30

RWH 5_ReorderLevel(02)	24	(Insuf)	24	24	24
RWH 5_ReorderLevel(03)	37	(Insuf)	37	37	37
RWH 5_SS(01)	23	(Insuf)	23	23	23
RWH 5_SS(02)	19	(Insuf)	19	19	19
RWH 5_SS(03)	28	(Insuf)	28	28	28
RWH 5_Total Lost Sales Cost	29,000				
RWH 5_Total Ordering Cost	109,200				
RWH 5_Total Handling Cost	26,280,000				
RWH 5_Total Safety Stock Cost	3,312,010				
RWH 5_Total Pipeline Cost	1,024,103				
RWH 5_Total Trucking Cost	3,802,061				
RWH 5_Overall Cost	34,556,374				
RWH 6 IWH Response Time	1.4375	0.05	0.41463	3.0065	364
RWH 6 Inbound Order Satisfaction	1				
RWH 6 Outbound Order Satisfaction	0.99954				
RWH 6_Inv(01)	30.318	0.57617	0	54	32
RWH 6_Inv(02)	19.016	0.40959	1	31	19
RWH 6_Inv(03)	40.289	0.76455	2	73	44
RWH 6_OrderUptoLevel(01)	54	(Insuf)	54	54	54
RWH 6_OrderUptoLevel(02)	31	(Insuf)	31	31	31
RWH 6_OrderUptoLevel(03)	73	(Insuf)	73	73	73
RWH 6_ReorderLevel(01)	44	(Insuf)	44	44	44
RWH 6_ReorderLevel(02)	26	(Insuf)	26	26	26
RWH 6_ReorderLevel(03)	59	(Insuf)	59	59	59
RWH 6_SS(01)	33	(Insuf)	33	33	33
RWH 6_SS(02)	20	(Insuf)	20	20	20
RWH 6_SS(03)	44	(Insuf)	44	44	44
RWH 6_Total Lost Sales Cost	46,000				
RWH 6_Total Ordering Cost	109,200				
RWH 6_Total Handling Cost	26,280,000				
RWH 6_Total Safety Stock Cost	4,446,430				
RWH 6_Total Pipeline Cost	1,575,210				
RWH 6_Total Trucking Cost	10,199,633				
RWH 6_Overall Cost	42,656,473				

Table E.4: Outputs of Regions

	Average	Half Width	Min	Max	Final Value
Region 5_Demand(1)	1.9997	0.09082	0	6	2
Region 5_Demand(2)	1.0817	0.10462	0	4	2
Region 5_Demand(3)	3.0612	0.06626	0	7	3
Region 5_LostSales(1)	0				
Region 5_LostSales(2)	0				
Region 5_LostSales(3)	0				
Region 5_Order Satisfaction	1				
Region 5_RWH Response Time	2.3298	0.03579	0.87977	3.6051	728
Region 5_Total Lost Sales	0				
Region 6_Demand(1)	3.975	0.07402	0	7	3
Region 6_Demand(2)	1.9701	0.06397	0	6	0
Region 6_Demand(3)	4.9757	0.07864	0	8	6
Region 6_LostSales(1)	0				
Region 6_LostSales(2)	0				
Region 6_LostSales(3)	1				
Region 6_Order Satisfaction	0.99863				
Region 6_RWH Response Time	1.3211	0.04916	0.312	2.7209	730
Region 6_Total Lost Sales	1				
Region 7_Demand(1)	5.9912	0.09558	0	9	5
Region 7_Demand(2)	2.979	0.07062	0	6	3
Region 7_Demand(3)	10.031	0.0801	0	13	11
Region 7_LostSales(1)	1				
Region 7_LostSales(2)	2				
Region 7_LostSales(3)	0				
Region 7_Order Satisfaction	0.99726				
Region 7_RWH Response Time	1.3248	0.04282	0.33359	2.8179	729
Region 7_Total Lost Sales	3				
Region 8_Demand(1)	2.0353	0.0731	0	5	2
Region 8_Demand(2)	1.0697	0.08718	0	4	1
Region 8_Demand(3)	2.9587	0.07303	0	6	2
Region 8_LostSales(1)	6				
Region 8_LostSales(2)	0				
Region 8_LostSales(3)	39				
Region 8_Order Satisfaction	0.97802				
Region 8_RWH Response Time	2.2127	0.03	0.97245	3.8947	728
Region 8_Total Lost Sales	45				

Region 9_Demand(1)	2.0216	0.07814	0	5	2
Region 9_Demand(2)	1.0878	0.07329	0	4	0
Region 9_Demand(3)	2.9889	0.08648	0	6	2
Region 9_LostSales(1)	21				
Region 9_LostSales(2)	1				
Region 9_LostSales(3)	44				
Region 9_Order Satisfaction	0.96286				
Region 9_RWH Response Time	2.2293	0.03484	0.46441	3.9718	727
Region 9_Total Lost Sales	66				
Region 10_Demand(1)	3.0612	0.0807	0	6	3
Region 10_Demand(2)	1.0598	0.06689	0	4	2
Region 10_Demand(3)	3.946	0.0813	0	7	4
Region 10_LostSales(1)	14				
Region 10_LostSales(2)	0				
Region 10_LostSales(3)	46				
Region 10_Order Satisfaction	0.97668				
Region 10_RWH Response Time	1.205	0.04345	0.21587	2.7401	729
Region 10_Total Lost Sales	60				
Region 11_Demand(1)	3.0201	0.08187	0	6	3
Region 11_Demand(2)	1.9939	0.07857	0	5	3
Region 11_Demand(3)	4.9949	0.07076	0	8	6
Region 11_LostSales(1)	19				
Region 11_LostSales(2)	0				
Region 11_LostSales(3)	70				
Region 11_Order Satisfaction	0.96571				
Region 11_RWH Response Time	1.2179	0.0357	0.21523	2.564	729
Region 11_Total Lost Sales	89				
Region 12_Demand(1)	1.9805	0.07369	0	5	2
Region 12_Demand(2)	0.96917	0.048	0	4	3
Region 12_Demand(3)	3.0037	0.09753	0	6	3
Region 12_LostSales(1)	0				
Region 12_LostSales(2)	0				
Region 12_LostSales(3)	0				
Region 12_Order Satisfaction	1				
Region 12_RWH Response Time	2.4256	(Corr)	0.83131	3.9656	728
Region 12_Total Lost Sales	0				
Region 13_Demand(1)	6.1159	0.08473	0	10	5
Region 13_Demand(2)	3.042	0.08004	0	6	3
Region 13_Demand(3)	8.973	0.05708	0	12	8

Region 13_LostSales(1)	11				
Region 13_LostSales(2)	6				
Region 13_LostSales(3)	42				
Region 13_Order Satisfaction	0.98354				
Region 13_RWH Response Time	1.3026	0.04984	0.32098	2.6304	729
Region 13_Total Lost Sales	59				
Region 14_Demand(1)	6.0663	0.05721	0	10	6
Region 14_Demand(2)	3.0174	0.08529	0	6	3
Region 14_Demand(3)	7.9794	0.08731	0	11	9
Region 14_LostSales(1)	0				
Region 14_LostSales(2)	0				
Region 14_LostSales(3)	0				
Region 14_Order Satisfaction	1				
Region 14_RWH Response Time	2.4407	0.05143	0.82422	4.2396	728
Region 14_Total Lost Sales	0				
Region 15_Demand(1)	1.0354	0.05272	0	5	1
Region 15_Demand(2)	1.0933	0.07652	0	4	0
Region 15_Demand(3)	1.9336	(Corr)	0	5	3
Region 15_LostSales(1)	7				
Region 15_LostSales(2)	1				
Region 15_LostSales(3)	11				
Region 15_Order Satisfaction	0.98356				
Region 15_RWH Response Time	1.3144	0.03165	0.31616	3.0067	730
Region 15_Total Lost Sales	19				
Region 16_Demand(1)	1.9709	0.06841	0	5	2
Region 16_Demand(2)	1.0379	0.06541	0	4	2
Region 16_Demand(3)	3.0612	0.0898	0	6	3
Region 16_LostSales(1)	9				
Region 16_LostSales(2)	0				
Region 16_LostSales(3)	18				
Region 16_Order Satisfaction	0.98903				
Region 16_RWH Response Time	1.3156	0.03819	0.31124	2.7282	729
Region 16_Total Lost Sales	27				
Region 17_Demand(1)	1.0623	(Corr)	0	4	3
Region 17_Demand(2)	1.0541	0.07997	0	4	3
Region 17_Demand(3)	1.9671	0.09161	0	5	1
Region 17_LostSales(1)	0				
Region 17_LostSales(2)	0				
Region 17_LostSales(3)	0				

Region 17_Order Satisfaction	1				
Region 17_RWH Response Time	2.4164	0.03718	1.024	3.8323	728
Region 17_Total Lost Sales	0				
Region 18_Demand(1)	2.072	0.06771	0	6	3
Region 18_Demand(2)	1.0724	0.07207	0	4	1
Region 18_Demand(3)	2.9595	0.09954	0	6	4
Region 18_LostSales(1)	2				
Region 18_LostSales(2)	0				
Region 18_LostSales(3)	0				
Region 18_Order Satisfaction	0.99863				
Region 18_RWH Response Time	1.4252	0.04509	0.41111	3.3361	730
Region 18_Total Lost Sales	2				
Region 19_Demand(1)	2.0405	0.07818	0	5	3
Region 19_Demand(2)	1.0535	0.08463	0	4	0
Region 19_Demand(3)	1.9835	0.05283	0	5	1
Region 19_LostSales(1)	0				
Region 19_LostSales(2)	1				
Region 19_LostSales(3)	0				
Region 19_Order Satisfaction	0.99863				
Region 19_RWH Response Time	1.427	0.02601	0.41246	2.8726	729
Region 19_Total Lost Sales	1				
Region 20_Demand(1)	2.0353	0.07801	0	6	2
Region 20_Demand(2)	1.0738	0.07843	0	5	1
Region 20_Demand(3)	2.0476	0.07338	0	5	2
Region 20_LostSales(1)	0				
Region 20_LostSales(2)	0				
Region 20_LostSales(3)	0				
Region 20_Order Satisfaction	1				
Region 20_RWH Response Time	1.3986	0.04222	0.4142	2.9309	729
Region 20_Total Lost Sales	0				
Region 21_Demand(1)	1.0598	0.071	0	4	2
Region 21_Demand(2)	1.093	0.07526	0	4	1
Region 21_Demand(3)	2.0304	0.07446	0	5	0
Region 21_LostSales(1)	0				
Region 21_LostSales(2)	0				
Region 21_LostSales(3)	0				
Region 21_Order Satisfaction	1				
Region 21_RWH Response Time	1.4382	0.04267	0.41142	2.8723	728
Region 21_Total Lost Sales	0				

Region 22_Demand(1)	6.0076	0.09839	0	10	5
Region 22_Demand(2)	2.9667	0.08953	0	6	3
Region 22_Demand(3)	8.9974	0.1108	0	12	9
Region 22_LostSales(1)	3				
Region 22_LostSales(2)	2				
Region 22_LostSales(3)	7				
Region 22_Order Satisfaction	0.99315				
Region 22_RWH Response Time	1.2095	0.03347	0.21275	2.8702	730
Region 22_Total Lost Sales	12				
Region 23_Demand(1)	1.9624	0.07861	0	5	3
Region 23_Demand(2)	1.1193	0.05071	0	4	0
Region 23_Demand(3)	4.046	0.07466	0	7	4
Region 23_LostSales(1)	1				
Region 23_LostSales(2)	0				
Region 23_LostSales(3)	2				
Region 23_Order Satisfaction	0.99726				
Region 23_RWH Response Time	1.1939	0.03891	0.21669	2.6503	729
Region 23_Total Lost Sales	3				