Analysis of an International Distribution Hub for Fast Moving Consumer Goods

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ABSTRACT

The focus of this research is creating a framework to accurately assess the benefits of hub capability in an international distribution network for fast moving consumer packaged goods. The traditional inventory centralization dilemma requires an evaluation of whether the reduction in holding costs outweighs the increases in transportation and handling costs. We developed a mixed integer programming model to determine the benefits of adding hub capability to Consumer Co.'s Northwest Latin American import supply chain.

Consumer Co.'s NWLA division imports products from Argentina, Brazil and Mexico to eleven countries within Central and South America, each operating a distribution center. By adding hub capability in the Colon Free Trade Zone, our model determined that the lowest cost could be achieved using a "Hybrid" solution, where some channels flowed through the hub and others were shipped direct. This network design would result in a 4.4% reduction in annual relevant costs. A counter-intuitive revelation was the fact that transportation costs could actually decrease. Similar to airlines, carriers can sometimes offer lower rates for indirect shipments passing through a high volume transit point instead of shipping the product directly through a less traveled route.

Hub capability in the Colon Free Trade Zone also provides Consumer Co. with the flexibility to tailor their supply chain to potential changes in the fluctuating Latin American environment. Increasing customer expectations can lead to scenarios with higher safety stocks, for which centralization can provide the highest benefits.

Thesis Supervisor: Professor Stephen C. Graves
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1. Introduction

The material presented in this thesis was collected in conjunction with our sponsor company referred to throughout the paper as Consumer Co. Their interest in a model to assess the cost benefits of introducing a distribution hub to service multiple countries in their supply chain was the motivation for our analysis. Though some of Consumer Co.'s products have only local appeal, others appeal to countries throughout a region and are thus produced centrally, often outside of the region, in order to gain production economies of scale.

1.1. Disclaimer

The information presented in the case in Chapter 2 of this thesis is based on actual data and conversations with our sponsor company. The actual name of the company and much of the data has been disguised as to not reveal private company figures. Pieces of the case have also been adapted to enhance the presentation.

1.2. Structure

The format of this thesis is structured to provide all relevant background and data in a case study format in Chapter 2. The case study is followed by Chapter 3 which presents an academic review of the potential benefits commonly associated with distribution hubs. Chapter 4 follows with a detailed analysis of our methodology used to evaluate the case. The solution and sensitivity analysis is presented in Chapter 5.

2 Case Study

Returning from the meeting with Jorge Diaz, Head of Operations for Consumer Co.'s Northwest Latin American (NWLA) Division, Carlos Garcia began to weigh the options in his mind. He and Jorge had just heard the proposal from a third-party logistics provider detailing the savings that his company, Consumer Co., could realize by flowing all of their import goods through an international distribution hub located in the Colon Free Trade Zone in Panama, rather than direct from the production countries to the regional distribution centers in the distribution countries. Not surprisingly, the third-party logistics provider had submitted a bid to manage the hub at a cost of $29 per pallet. Carlos needed to assess this proposal quickly and have a recommendation for his boss by the next staff meeting. Was it really possible to add a step to the supply chain and still decrease costs? If so, was Panama the optimal location for such a distribution facility?

2.1 Company Background

Consumer Co. is a large multi-national manufacturer of consumer packaged goods with product lines ranging from food items to personal care items. As a well-established global company, Consumer Co. consists of multiple operating divisions throughout the world organized based on geography. Their divisions include, among others, Europe, North America, Central America, and Northern South America. A recent move by corporate headquarters combined the Central American division with the Andina region in an attempt to gain synergies and increase total company profitability.

The combined Central American and Northern South American divisions formed a new division dubbed NWLA which encompasses the following eleven countries within the region from North to South; Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Ecuador, Peru, and Bolivia (see green highlighted countries in Figure 1). Within each of the eleven countries of the newly-created division, Consumer Co. operates a regional distribution center (RDC) that receives products from international and local production sources and then ships to local retailers who are Consumer Co.'s customers.

Figure 1: Consumer Co's Countries of Operation

The new NWLA replenishment team led by Jorge Diaz was composed of demand planners in each country as well as a central planning team focused on product lines to monitor the replenishment systems and efficiently execute the fulfillment process. Some of the primary concerns in executing the supply chain strategy were deciding on sourcing locations, maintaining an accurate demand forecast, monitoring the order lead times, and scrutinizing the duties and tariffs assessed on imports.

2.2 Sourcing Decision

For each country and each product category, the sourcing decision as to whether to produce locally or import from an international production facility was determined by corporate and was largely dictated by the sales reach of the product. Products that had a limited geographical sales area were typically produced locally to minimize transportation costs. Those products with wide geographic reach were typically produced at one of three manufacturing plants that the company owned in Argentina, Brazil, and Mexico (see orange highlighted countries in Figure 1) in order to consolidate volume and create economies of scale. In the case of Consumer Co., the food products were differentiated based on local tastes and typically had well developed local reputations. For this reason, most food products were produced and distributed locally. On the other hand, the personal care products tended to have wide-reaching demand throughout the region and therefore were produced in the large international production facilities. Figure 2 below diagrams the current supply chain for imported items.

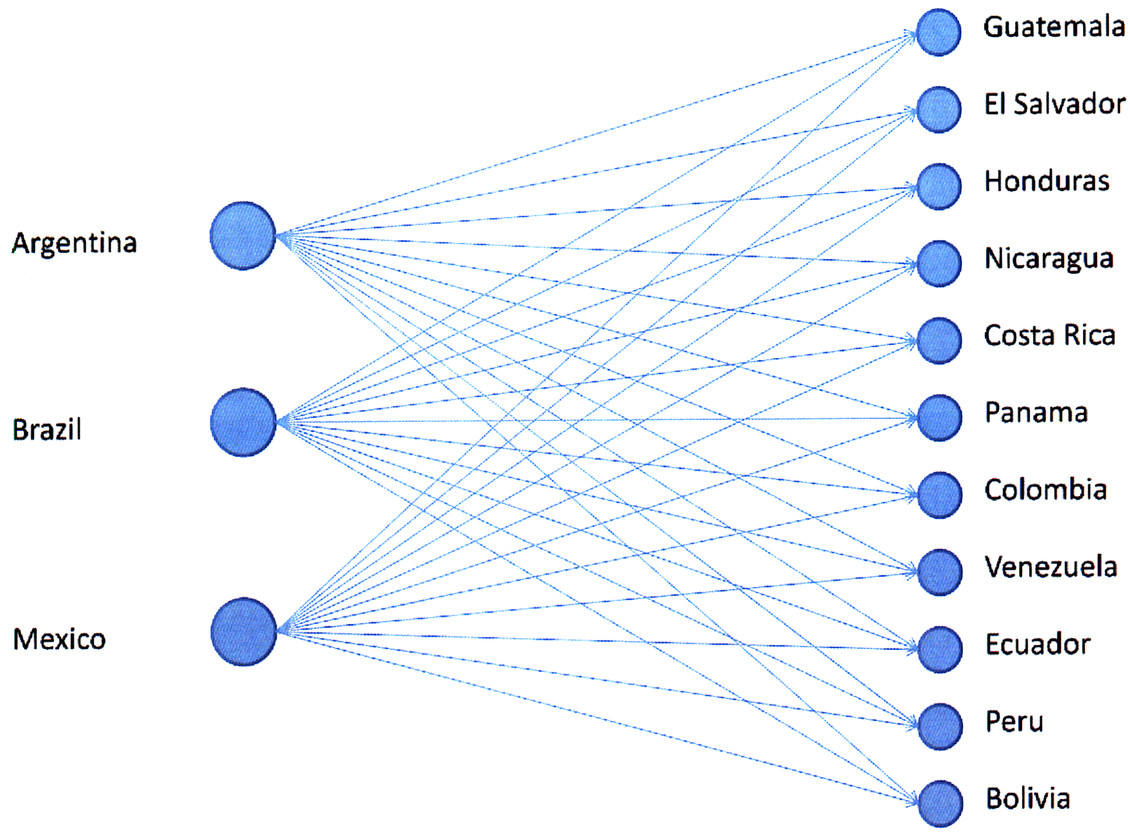

Figure 2: Consumer Co's Current Supply Chain Design

Although the production economies of scale often made it cheaper to produce goods at a shared international production facility, items produced at these plants incurred additional costs in movement to the distribution centers within each of the countries. These costs include transportation costs, duties, and tariffs.

2.3 Import Ordering and Shipping Process

Consumer Co. maintains a centralized Distribution Requirements Planning (DRP) system into which each country enters forecasted demand. Once per week, the DRP compares the item inventory levels to the order points which are based on the country specific lead time and desired service level to determine if at a country level there is enough demand to generate a transit order. If the transit order does not fill a container, the order may be delayed in shipping until the next order cycle. If the order is urgent, more expensive options can be used such as adding overstock to fill the container, shipping the container at less than full capacity, or shipping a smaller container.

Consumer Co. considers utilization of full container shipping critical to minimizing shipping costs per unit. With a high fixed shipping cost of moving a container from the production facility to the RDCs in each of the countries, it is critical that the container is shipped at full capacity. Utilization improvement can be achieved by holding the order until the next order cycle or alternatively by increasing the current order volume in order to maximize container utilization. These alternatives employed by Consumer Co. increase either lead time or holding costs once the excess product reaches the RDC. Table 1 below details Consumer Co.'s current container utilization.

Dest.\Source	Argentina	Brazil	Mexico
Guatemala	80%	95%	71%
Honduras	75%	97%	78%
El Salvador	75%	100%	80%
Nicaragua	85%	91%	83%
Costa Rica	85%	100%	71%
Panamá	25%	100%	75%
Colombia	89%	95%	93%
Venezuela	98%	97%	96%
Ecuador	95%	96%	86%
Perú	93%	95%	82%
Bolivia	93%	90%	79%

Table 1: Container Utilization by Destination/Source

In shipping from the international production facilities to the RDCs, the product must flow through three stages of shipping after it is produced. The first stage is the shipping from the production facility's warehouse to the port in the country of production by a hired carrier. This stage is referred to as source-inland shipping by Consumer Co. and is the same for each of the countries serviced by a production facility.

As the product passes from the first stage to the second stage, a Free on Board (FOB) expense is incurred at customs. Once this is paid the product enters the second shipping stage referred to as international freight by Consumer Co. This stage involves the ocean freight shipping from the origin port to the destination country port. Like the first shipping stage, it is also outsourced to a hired carrier and the costs vary based mainly on the distance of the destination country from the production country but also varies depending on the route.

After clearing customs at the destination port, the shipment moves into the third and final stage referred to as destination-inland shipping which includes the movement of goods from the port to the RDC. This stage is handled by third-party truck; its cost can vary based on the rates in the country and also the distance of the RDC from the port.

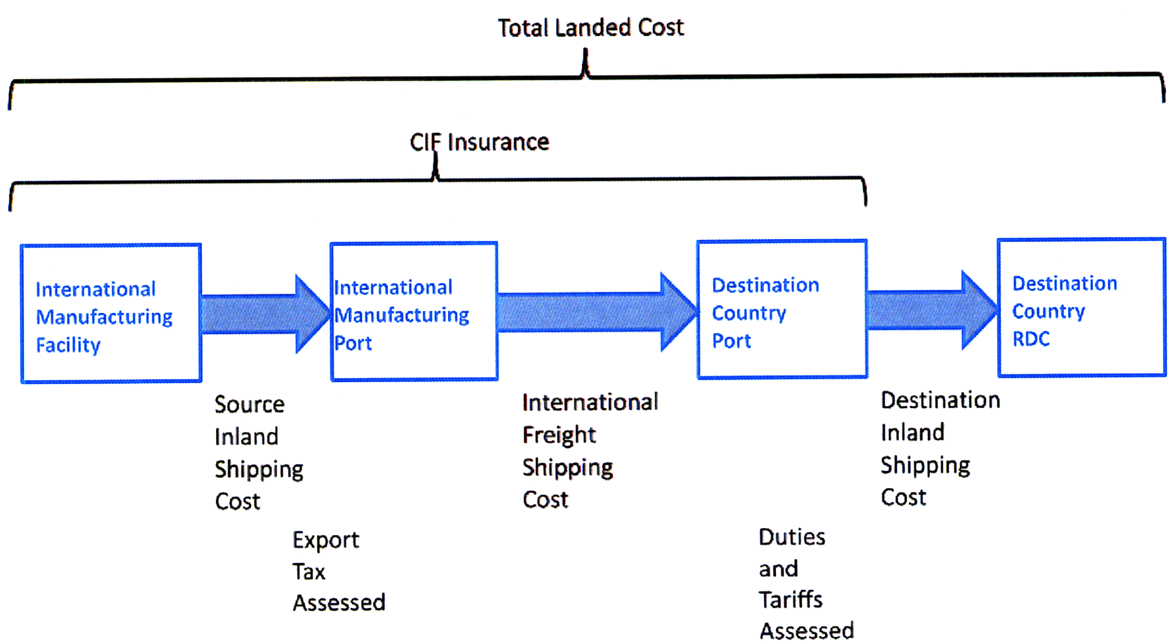

Figure 3: Consumer Co.'s Import Supply Chain

2.3.1 Demand Forecasting

The DRP system for the NWLA division places orders for each country in the region to the production facility based on their independent forecasts and inventory levels, as well as the desired item fill rates for their retail customers. Due to the nature of Consumer Co.'s import products, there is virtually no seasonality in the monthly demand. Table 2 below details a two year order history.

	Argentina		Brazil		Mexico	
Destination Country	Average Yearly Demand (Pallets)	Transfer Price per Pallet	Average Yearly Demand (Pallets)	Transfer Price per Pallet	Average Yearly Demand (Pallets)	Transfer Price per Pallet
Guatemala	868	$ 1,825	457	$ 1,507	1,479	$ 1,148
Honduras	689	$ 1,530	297	$ 1,697	890	$ 1,600
El Salvador	861	$ 1,401	611	$ 1,503	1,181	$ 1,300
Nicaragua	521	$ 1,511	164	$ 1,422	1,631	$ 1,550
Costa Rica	694	$ 1,926	1,360	$ 1,463	1,974	$ 1,245
Panamá	163	$ 1,567	365	$ 1,506	974	$ 1,277
Colombia	1,539	$ 2,243	2,134	$ 1,527	10,465	$ 1,117
Venezuela	3,278	$ 2,101	6,646	$ 1,487	11,553	$ 1,251
Ecuador	1,790	$ 2,259	1,073	$ 1,608	4,746	$ 1,066
Perú	755	$ 1,651	2,453	$ 1,554	2,171	$ 1,057
Bolivia	1,600	$ 1,661	1,619	$ 1,339	1,392	$ 1,011

Table 2: Average Yearly Demand and Average Value per Pallet by Destination/Source

The desired item fill rate for each of the NWLA countries is independently set by the management of the country operations. Because the cost to maintain certain item fill rates differs between countries, it is common for different source-destination country combinations to have different item fill rate targets. Table 3 below shows the current actual item fill rates achieved for each of the NWLA countries.

Dest.\Source	Argentina	Brazil	Mexico
Guatemala	89%	95%	91%
Honduras	92%	95%	92%
El Salvador	94%	95%	92%
Nicaragua	98%	97%	97%
Costa Rica	89%	94%	88%
Panamá	96%	99%	95%
Colombia	94%	97%	96%
Venezuela	85%	86%	86%
Ecuador	88%	93%	90%
Perú	93%	96%	96%
Bolivia	94%	93%	91%

Table 3: Item Fill Rates by Destination/Source

For replenishment items, historical sales demand data is systematically analyzed for volume and trend to determine order quantities needed from the international production facility. This forecasting accuracy is complicated by the extended lead times for imported products as well as the number of products that Consumer Co. produces at its international production facilities. With lead times often reaching 45-60 days (see Table 5 for details) for each of the nearly 700 unique imported items, Consumer Co. must ship containers with a highly inaccurate forecast. Table 4 below summarizes the forecasting department's accuracy metric, expressed as a Mean Absolute Percent Error (MAPE), comparing actual demand in a month to the forecast just prior to the start of the month (N), one month prior (N-1), and two months prior (N-2).

Period	Average MAPE
N	33%
N-1	39%
N-2	44%

Table 4: Forecast Mean Absolute Percent Error Over Time

2.3.2 Lead time performance

Sourcing from international production facilities also impacts the lead time from order placement to order receipt at the various RDCs. The increased shipping distances as well as time spent in customs cause the delivery lead time for products to be long and have substantial variability. See Table 5 below for details of lead times by Destination-Source.

	Argentina		Brazil		Mexico	
Destination Country	LT (Days)	LT Std Dev (Days)	LT (Days)	LT Std Dev (Days)	LT (Days)	LT Std Dev (Days)
Guatemala	49	15	48	12	14	3
Honduras	43	13	42	10	15	3
El Salvador	57	17	40	10	14	3
Nicaragua	68	21	47	11	17	4
Costa Rica	66	20	38	9	18	4
Panamá	35	11	36	9	17	4
Colombia	39	10	37	7	23	7
Venezuela	62	18	36	8	32	5
Ecuador	33	11	46	8	21	6
Perú	35	12	42	15	28	7
Bolivia	11	18	14	8	41	5

Table 5: Lead Time Performance

Although, local production would reduce transportation distances and provide a shorter lead time, Consumer Co. does not do this because the economies of scale savings achieved by combining volume to international production facilities more than offsets the savings in inventory that would be attained with shorter lead times.

2.4 Duties and Tariffs

The duties and tariffs within the NWLA region vary based on product value, source country, destination country, and product category.

2.4.1 Product Valuation for Duty Purposes

The product valuation for duty and tariff purposes is composed of multiple parts including transfer price, shipping costs, and insurance costs.

The transfer price of the product is the price that each country pays to the production facility for each unit ordered. This price is set by corporate and covers the cost of producing the product plus some markup to cover overhead costs at the production facilities.

The shipping costs and FOB expenses from the shipping country to the receiving port for the entire order are divided among each of the products in the order. Adding these costs to the transfer price of the product can in many instances significantly increase the tax basis for the product. Table 6 below details the transportation cost per pallet for each of Consumer Co.'s source and destination combinations.

Dest.\Source	Argentina	Brazil	Mexico
Guatemala	$ 321	$ 255	$ 48
Honduras	$ 240	$ 327	$ 38
El Salvador	$ 525	$ 459	$ 222
Nicaragua	$ 235	$ 250	$ 17
Costa Rica	$ 877	$ 481	$ 433
Panamá	$ 287	$ 281	$ 180
Colombia	$ 371	$ 422	$ 135
Venezuela	$ 722	$ 619	$ 513
Ecuador	$ 656	$ 494	$ 350
Perú	$ 314	$ 379	$ 259
Bolivia	$ 153	$ 259	$ 178

Table 6: Transportation Cost per Pallet by Destination/Source

An additional cost added to the value of the product for tax purposes is the insurance cost. Again this cost is based on the value of the product and covers against loss or damage to the product in the supply chain. For Consumer Co., this cost represents only a small value, often under $100, for each container imported.

The combination of these costs in the import process is referred to as the Cost, Insurance, and Freight (CIF) price by Consumer Co. Import duties and tariffs are assessed based on this calculated CIF price. The amount of duties and tariffs depends on source country, product category and destination country of the products. Countries with strong alliances or treaties typically charge one another lower duties/tariffs while those with poor relations often charge higher rates for imports. The weighted average duties charged for Consumer Co.'s imported product lines are shown in Table 7.

Dest.\Source	Argentina	Brazil	Mexico
Guatemala	15%	15%	3%
Honduras	15%	15%	18%
El Salvador	15%	15%	8%
Nicaragua	15%	17%	2%
Costa Rica	31%	20%	18%
Panamá	15%	15%	10%
Colombia	3%	8%	0%
Venezuela	12%	13%	20%
Ecuador	17%	14%	20%
Perú	9%	9%	9%
Bolivia	0%	4%	0%

Table 7: Average Duties Paid by Consumer Co.

Once the duties and tariffs are assessed and divided among the products being imported, Consumer Co. determines a new value of the product, referred to as the Total Landed Cost which also includes the unit costs of local freight and warehouse handling. This new value, which includes all charges in the import process, is used for the assessment of holding costs by each of the countries. The current inventory carrying charge used by Consumer Co. for the countries is shown in Table 8 below.

DC	Carrying Charge
GUATEMALA	7.0%
EL SALVADOR	7.0%
HONDURAS	7.0%
NICARAGUA	7.0%
COSTA RICA	7.0%
PANAMA	7.0%
COLOMBIA	8.0%
VENEZUELA	35.8%
ECUADOR	10.7%
PERU	6.3%
BOLIVIA	13.5%

Table 8: Inventory Carrying Charge by Country

2.4.2 Colon Free Trade Zone

The Colon Free Trade Zone (CFZ) in Panama was an interesting alternative for a hub since product arriving there does not have to be nationalized. Import duties and tariffs are not applied unless the product is invoiced to a domestic customer. In the case of Consumer Co., this would be their RDC in Panama. Panama is also a country that is investing significantly in their transportation infrastructure, which would reduce overall logistics costs in the long term.

2.5 Case Wrap-up

As Carlos contemplated his decision and the impact it would have on Consumer Co.'s supply chain, he wondered if there were savings to be achieved. The potential for reduced inventory and taxes was appealing, but the increased spend to outsource the operation of the distribution hub and increased transportation distances may offset any savings. In order to assess the combined impact of these costs, a model was needed to determine if there were supply chain cost savings that could be achieved by adding an international distribution hub.

3 Expected Impacts of Network Redesign with Hub Capability

In Consumer Co.'s pursuit of supply chain cost savings, they pondered the idea of introducing a distribution hub, most likely into Panama, into their supply chain. Adding this capability into the supply chain would increase third-party logistics spend. Higher transportation costs could also be incurred since containers would now have to travel longer distances. Our analysis will determine if these additional costs will be offset by potential supply chain cost savings. These savings would mainly come from a reduction in Consumer Co.'s considerable inventory levels of their import product lines. Lower safety stock could be achieved by risk pooling of forecasts errors over the lead time, by reducing lead time variability, and by consolidating country demand to allow more frequent replenishments. Figure 4 below diagrams the proposed new distribution network for Consumer Co.

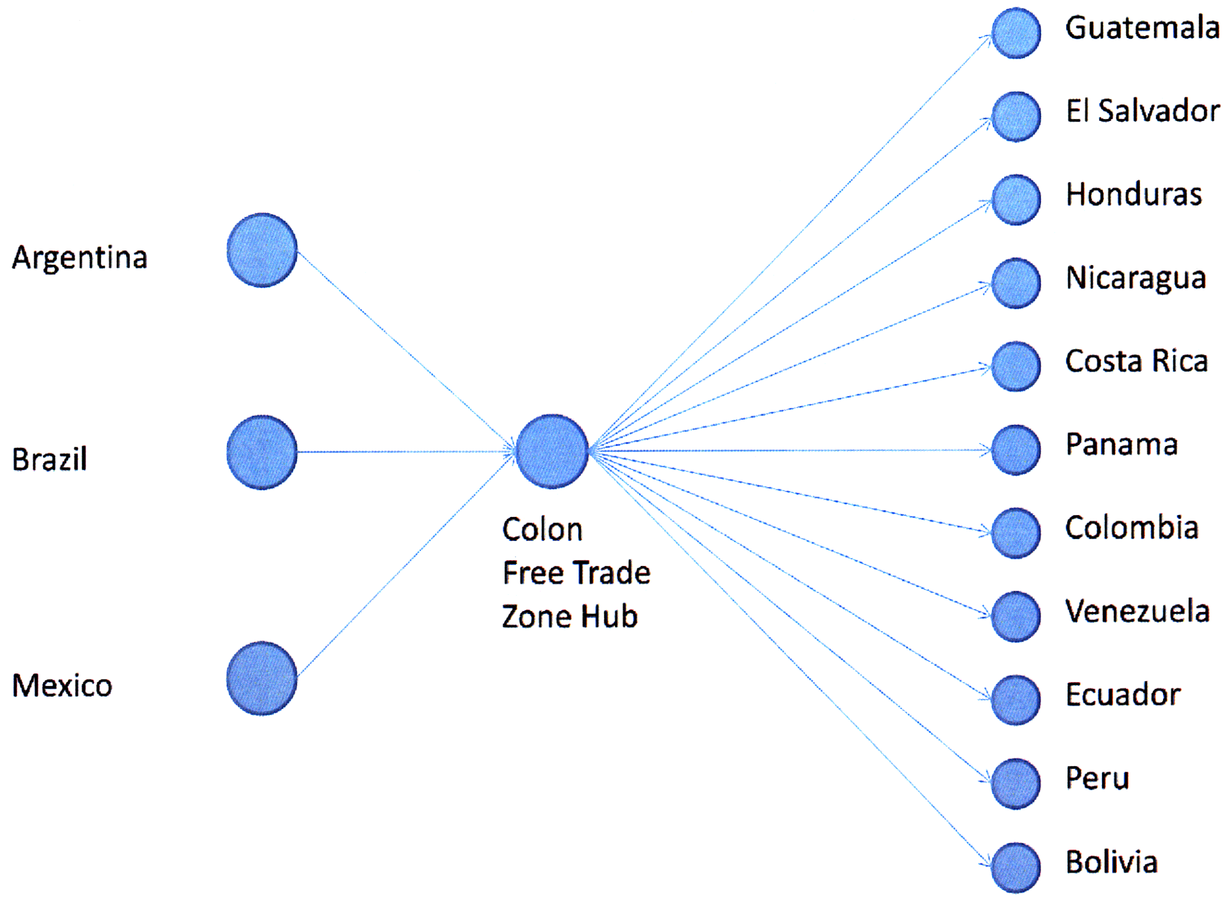

Figure 4: Consumer Co's Proposed Supply Chain Design

3.1 Risk Pooling and Postponement

The first potential supply chain cost savings from implementing a distribution hub is the pooling of each country's demand variation risk. By aggregating or pooling this risk to a regional level instead of a country level, hub demand would have a smaller coefficient of variation than demand for individual regional warehouses and therefore would require less safety stock over the order lead time as discussed by Kaminsky (2003). This improvement in the accuracy of aggregated forecasts versus disaggregated forecasts supports this hypothesis by Consumer Co. Our research will determine if Consumer Co. will indeed experience reduced forecast error; if so, we will determine the impact that aggregating forecasts will have on network inventory levels and costs.

In order to take advantage of any improvements in forecasting through aggregation, Consumer Co. would need to implement a postponement process in which final distribution decisions are not made until the product reaches the hub. At that time, they could redistribute product from countries which are underperforming to forecast to those which are outperforming forecasts. This is particularly important due to the increase in forecast accuracy from original order time to the arrival time at the hub. In addition, safety stock at the hub would only have to cover for variability over a shorter time period.

3.2 Reduced Fixed Order Cost and Minimum Order Size

A second potential benefit of consolidating demand through a distribution hub is the reduction in the fixed cost per order which in Consumer Co.'s case is largely made up of container transportation costs. Sharing the large transportation cost of an order among countries would reduce the fixed cost per order per country and therefore lower their economic order quantity (EOQ). Using the EOQ equation, it can be shown that a reduction in the fixed ordering cost by sharing the transportation cost to the distribution hub would allow the countries with low volume to order more frequently and consolidate shipments from multiple production facilities at the hub. The benefits of this would be reduced inventory holding costs without increasing shipping costs.

3.3 Increased Adaptability to Fluctuating Free Trade Agreements

Another potential benefit of consolidating demand through a distribution hub is the reduction in the total duties and tariffs levied on imported product. A more flexible network design would allow Consumer Co. to quickly take advantage of potential saving on taxes paid on transportation. In Latin America, where free trade agreements were constantly in flux, these potential savings were something to keep an eye on.

There are currently many barriers to trade within the NWLA region due to the lack of an all-encompassing free trade agreement. There are many different trade agreements currently in effect, but not a single agreement that includes all of the production and distribution countries of Consumer Co. A brief overview of the main agreements in Latin America is presented below (Sweat, 2008).

The Andean Pact was signed in 1969 to reduce trade barriers and create an economic union among the member countries of Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela. Although the Pact helps to promote trade among the member countries, two member countries, Chile and Venezuela, have withdrawn since the signing of the Pact which has reduced its overall effectiveness with regard to easing trade restrictions within the region.

A second agreement within the region that impact many of the countries is the Central American Common Market (CACM). At current, the CACM agreement seeks to reduce trade barriers between its member nations which include Guatemala, El Salvador, Honduras, Nicaragua, and Costa Rica. Consumer Co. imports personal care products to these countries, but like the Andean countries it does its production in countries not included in the agreement and therefore does not gain benefit from this agreement.

The Group of Three (G3) trade agreement brought Mexico, Colombia, and Venezuela into an agreement meant to reduce tariffs and promote trade between the countries. This agreement was promising as it would link one of Consumer Co.'s three production facilities to two of its major distribution markets. This promise decreased somewhat with the withdrawal of Venezuela from the agreement in 2006. After the withdrawal of Venezuela, Nicaragua signed into the agreement with Mexico and Colombia.

An additional agreement that seeks to eliminate trade barriers such as high tariffs is Mercosur, which branched out from the Asociación Latinoamericana de Integración (ALADI) agreement. Current full member countries include Argentina, Brazil, Paraguay, Uruguay, and Venezuela with associate member countries of Chile, Bolivia, Colombia, Ecuador and Peru. The Mercosur pact like the G3 pact links some of the production sites for Consumer Co. with some of their distribution markets, but fails to link all production to all distribution within the region.

Because none of the trade agreements link all eleven countries of the NWLA region to the three countries of import production, duties and tariffs are levied against import product and shipping costs. By shipping through an international distribution hub, Consumer Co. believes that they can reduce overall duties. By leveraging a free trade zone like the Colon Free Zone in Panama, Consumer Co. will reduce overall tariffs since the tariff at the destination country will be assessed on the value of the product plus only the shipping from the CFZ and not the total value of shipping from the source country. Due to the high correlation between shipping costs and distance, the proximity of the

CFZ could help to reduce overall duties and tariffs. Furthermore, the CFZ does not charge duties for imported product that is to be re-exported.

3.4 Expected Benefits Conclusion

The combination of the above factors and costs made the final analysis challenging. The potential for reduced inventory was appealing, but the increased spend to outsource the operation of the distribution hub and increased transportation distances may offset any savings achieved. Another potential benefit that Consumer Co. expected to achieve was a decrease in obsolete product inventory and write-offs. In order to evaluate the combined impact of these costs, a model was needed to determine if there were supply chain cost savings that could be achieved by adding an international distribution hub.

4 Building the Model

To evaluate the benefits of an international distribution hub for Consumer Co., we developed a model to predict the NWLA region's supply chain costs if it had the option of shipping products from production countries to a distribution hub in a free trade zone and allow RDC's to source from it. The model was calibrated to accurately match the actual annual replenishment costs and service levels. Our analysis was focused on transportation, holding and handling costs for the company's primary import product line.

Each production country and RDC was treated as a node in the system, as was the distribution hub. The flow of pallets through the model begins when they leave the production country and ends when they are stored at an RDC. The units of data are pallets. Pallets have a unit cost equal to the average actual transfer price from the production facility and acquire additional costs as they move through the supply chain. Our focus was on minimizing annual relevant costs while maintaining the current actual fill rates to customers.

Duties and tariffs applied to the shipping cost are included in the model as part of the total landed cost. Duties and tariffs applied to the original transfer price were not, since this amount depends only on product flow through the RDC's, and this remains constant in our model. However, duties and tariffs applied to the original product were considered as part of the valuation of inventory when considering holding costs.

Some supply chain variables such as distribution to customers, duties paid on transfer price, handling costs at the RDC's and manufacturing costs were not included in the model due to their lack of relevance to the hub decision. Overhead, shrinkage, bias in the forecast, and life-cycle generated overstock were other variables not included in the model.

The goal of our model is to find a solution that minimizes the total relevant costs of transportation, holding and handling. The objective function is stated as:

Objective Function: Minimize Total Relevant Costs (1)

Total Relevant Costs = Transportation + Holding + Hub Handling (2)

Transportation Costs = Direct + Hub Inbound + Hub Outbound (3)

Holding Costs = Pipeline + Cycle + Safety Stock (4)

Notation	**Description**	**Comment**
i	Node representing production countries	1,2,3
j	Node representing distribution centers	1,2,3,4,5,6,7,8,9,10,11
z	Node representing hub	
H_{ij}	Flow Binary Variable $H_{ij} = 0$ when node j receives product from node i directly from node i $H_{ij} = 1$ when node j receives product from node i from the hub	Decision Variable

M	Hub Safety Stock Binary Variable $M = 0$ when hub is cross-dock and holds no safety stock $M = 1$ when hub holds safety stock	Decision Variable
D_{ij}	Annual demand in pallets at node j for product coming from node i	Fixed
P_j, P_z	Handling cost per pallet at node j or z	Fixed
L_i	Pallet capacity per container from node i	Fixed
L_{zj}	Pallet capacity per container from hub to node j, calculated using a weighted average	$\frac{\sum_{i=1}^{3}(H_{ij} * D_{ij} * L_i)}{\sum_{i=1}^{3}(H_{ij} * D_{ij})}$
U_{ij}, U_{iz}, U_{zj}	Container utilization from node to node	Fixed Value between 0 and 1
Q_{ij}, Q_{iz}, Q_{zj}	Order quantity from node to node expressed in pallets	Calculation expressed in equations (14),(15),(16)

X_{ij}	Duties and tariffs per $ imported from node i to node j	Fixed Value between 0 and 1
X_{zj}	Average duties and tariffs per $ imported from hub to node j, calculated using a weighted average	Value between 0 and 1 $\frac{\sum_{i=1}^{3}(H_{ij} * D_{ij} * X_{ij})}{\sum_{i=1}^{3}(H_{ij} * D_{ij})}$
T_{ij}, T_{zj}	International shipping cost per container from node to node	Fixed Includes Source Inland, FOB Expense, International Freight and Insurance Costs
F_j	Local shipping cost per container at node j from hub or node i	Fixed
R_{iz}	Cost per container from node i to hub, which pays no duties and tariffs on transportation	Fixed. No duties or tariffs paid.
R_{zj}	Cost per container from hub to node j, which pays duties on all operations incurred to that point	$T_{zj} + \lfloor R_{iz} + (L_{zj} * U_{zj} * P_Z) + T_{zj} \rfloor * X_{zj} + F_j$
R_{ij}	Cost per container from node i to node j	$T_{ij} + T_{ij} * X_{ij} + F_j$

A_{ij}	Average value per pallet shipped from node i to node j	Fixed
B_{ij} , B_{iz} , B_{zj}	Average value per pallet stocked at a node	Calculations expressed in equations (9),(10),(11)
W_{ij} , W_{iz} , W_{zj}	Lead Time from node to node	Fixed
V_{ij} , V_{iz} , V_{zj}	Lead Time standard deviation from node to node	Fixed
E_{ij}	Fill Rate to customers at node j for product sourced from node i	Fixed Value between 0 and 1
E_{zj}	Fill Rate to customers at node j for product sourced from hub, calculated using a weighted average	Value between 0 and 1 $\frac{\sum H_{ij} * D_{ij} * E_{ij}}{\sum H_{ij} * D_{ij}}$
E_z	Fill Rate to nodes from hub, typically a modest value as to avoid redundancy in safety stock	Fixed at 70% Value between 0 and 1
C_j , C_z	Carrying charge at node	Fixed

s_{ij}	Standard deviation of daily forecast errors for product sourced from node i at node j	Fixed
s_{zj}	Standard deviation of daily forecast errors for product sourced from hub to node j	$\sqrt{\sum_{i=1}^{3}\left(H_{ij} * s_{ij}^2\right)}$
σ_{ij}, σ_{iz}, σ_{zj}	Total standard deviation of forecast errors during a shipment from one node to another	Calculation expressed in equations (20),(23),(27)
k_{ij}, k_{iz}, k_{zj}	Represents the number of σ 's that need to be covered in order to provide a given fill rate	Calculation expressed in equation (28) and (29)
$G_u(k_{ij})$, $G_u(k_{iz})$, $G_u(k_{zj})$	Unit Normal Loss Function used to find the minimum k that satisfies a given fill rate	Calculation expressed in equation (28) and (29)

Table 9: Description of Model Notation

Transportation Cost

The transportation cost was estimated by calculating the amount of volume flowing through each of our channels. Then we calculated the number of shipments required to fulfill this amount and multiplied them by the cost per shipment of each respective channel.

Direct

$$\sum_{i=1}^{3} \sum_{j=1}^{11} \left(\frac{(1 - H_{ij}) * D_{ij}}{L_i * U_{ij}} * R_{ij} \right) \tag{5}$$

Hub Inbound

$$\sum_{i=1}^{3} \left(\frac{\sum_{j=1}^{11} (H_{ij} * D_{ij})}{L_i * U_{iz}} * R_{iz} \right) \tag{6}$$

Hub Outbound

$$\sum_{j=1}^{11} \left(\frac{\sum_{i=1}^{3} (H_{ij} * D_{ij})}{L_{zj} * U_{zj}} * R_{zj} \right) \tag{7}$$

Hub Handling Cost

Handling costs at the Third Party Logistics (3PL) hub are proportional to the amount of pallets shipped. We must simply calculate the annual demand flowing through the hub and multiply it by the quoted handling cost per pallet:

Hub Handling Cost

$$P_z * \sum_{i=1}^{3} \sum_{j=1}^{11} H_{ij} * D_{ij} \tag{8}$$

Evaluating inventory at different stages of the supply chain

To calculate holding costs we required the average value of a pallet stocked at the hub and at the distribution centers. Pallets are shipped to distribution centers from factories valued at a predetermined transfer price. On their trip to the distribution centers they accumulate costs of freight, duties, tariffs and handling. These costs are added to the transfer price out of the factory in order to measure the holding costs at the distribution centers. This correctly penalizes the investment in inventory with the opportunity cost of its full expenses. This valuation varies depending on which echelon in the supply chain it is located. Pipeline stock was valued at the cost of its subsequent echelon.

Average value per pallet sourced from node i and stocked at node j

$$B_{ij} = A_{ij} * (1 + X_{ij}) + \frac{R_{ij}}{(L_i * U_{ij})} + P_j \tag{9}$$

Average value per pallet sourced from node i and stocked at hub

$$B_{iz} = \frac{\sum_{j=1}^{11}\left[H_{ij} * D_{ij} * (A_{ij} + \frac{R_{iz}}{L_i * U_{iz}})\right]}{\sum_{j=1}^{11}(H_{ij} * D_{ij})} + P_z \quad (10)$$

Average value per pallet sourced from hub and stocked at node j

$$B_{zj} = \frac{\sum_{i=1}^{3}\left[\left(A_{ij} * (1 + X_{ij}) + \frac{R_{iz}}{L_i * U_{iz}}\right) * H_{ij} * D_{ij}\right]}{\sum_{i=1}^{3}\left(H_{ij} * D_{ij}\right)} + \frac{R_{zj}}{(L_{zj} * U_{zj})} + P_j + P_z \quad (11)$$

Calculating Pipeline Stock

From an application of Little's Law, Little (1961), the inventory in transit in a system equals the length of the delay multiplied by the frequency of demand into the system.

Pipeline Stock Holding Cost

$$C_z * \sum_{i=1}^{3}[B_{iz} * W_{iz} * \sum_{j=1}^{11}\left(H_{ij} * \left(\frac{D_{ij}}{365}\right)\right)] +$$
$$\sum_{j=1}^{11} C_j * [\left(B_{zj} * W_{zj} * \sum_{i=1}^{3}\left(H_{ij} * \frac{D_{ij}}{365}\right)\right) + \left(\sum_{i=1}^{3}\left(B_{ij} * W_{ij} * (1 - H_{ij}) * \frac{D_{ij}}{365}\right)\right)] \quad (12)$$

Calculating Cycle Stock

Cycle Stock Holding Cost

$$C_z * \sum_{i=1}^{3}\left(B_{iz} * \frac{Q_{iz}}{2}\right) + \sum_{j=1}^{11} C_j * [\left(B_{zj} * \frac{Q_{zj}}{2}\right) + \sum_{i=1}^{3}\frac{B_{ij} * Q_{ij}}{2}] \quad (13)$$

First we determined ordering quantities considering the restrictions of ordering in multiples of 40 foot containers of a fixed capacity, average utilization, and shipment frequency restrictions. RDC's with high levels of demand for which a container represents less than a week of demand were assigned order quantities equal to a week's worth of demand. This is due to the minimum frequency with which Consumer Co.'s carriers travel on the shipping lanes we are considering. RDC's with low levels of demand for which a container represents more than a week of demand were assigned an order quantity of one container.

Average order quantity from node i to node j

$$Q_{ij} = (1 - H_{ij}) * \text{Max}(7 * (\frac{D_{ij}}{365}), L_i * U_{ij}) \quad (14)$$

Average order quantity from node i to hub

$$Q_{iz} = \text{Max}\ (7 * \frac{\sum_{i=1}^{3} H_{ij} * D_{ij}}{365}, L_i * U_{iz}) \quad (15)$$

Average order quantity from hub to node j

$$Q_{zj} = \text{Max}\ (7 * \frac{\sum_{j=1}^{11} H_{ij} * D_{ij}}{365}, L_{zj} * U_{zj}) \quad (16)$$

Calculating Safety Stock

Safety Stock Holding Cost

$$C_z * \sum_{i=1}^{3} \left(B_{iz} * k_{iz} * \sigma_{iz}\right) + \sum_{j=1}^{11} C_j * [B_{zj} * k_{zj} * \sigma_{zj} + \sum_{i=1}^{3} \left(B_{ij} * k_{ij} * \sigma_{ij}\right)] \tag{17}$$

Calculating safety stock required some processing of the elements of equation (17) before inserting them into it. First we needed to calculate the total standard deviation of forecast errors over the lead time of a shipment from one node to another, including possible variations in the lead time itself. Then we calculated the unit normal loss function in order to find the number of standard deviations of forecast errors over the lead time to cover in order to provide a specified fill rate.

σ_{ij} **(direct)**

1. Calculate standard deviation of forecast errors over the lead time

$$\sigma_{ij} = \sqrt{(1 - H_{ij}) * s_{ij}^2 * W_{ij}} \tag{18}$$

2. Include variance of the lead time

$$\sigma_{ij} = \sqrt{(1 - H_{ij}) * s_{ij}^2 * W_{ij} + \left(\frac{(1 - H_{ij}) * D_{ij}}{365}\right)^2 * \left(V_{ij}\right)^2} \tag{19}$$

3. Include order frequency for those distribution centers ordering in weekly periods

$$\sigma_{ij} = \sqrt{(1 - H_{ij}) * s_{ij}^2 * (7 + W_{ij}) + \left(\frac{(1 - H_{ij}) * D_{ij}}{365}\right)^2 * \left(V_{ij}\right)^2} \tag{20}$$

σ_{iz} **(hub inbound)**

1. Calculate standard deviation of demand over the lead time

$$\sigma_{iz} = M * \sqrt{W_{iz} * \sum_{j=1}^{11} \left(H_{ij} * s_{ij}^2\right)} \tag{21}$$

2. Include variance of the lead time

$$\sigma_{iz} = M * \sqrt{W_{iz} * \sum_{j=1}^{11} \left(H_{ij} * s_{ij}^2\right) + \left(V_{iz}\right)^2 * \sum_{j=1}^{11} \left[H_{ij} * \left(\frac{D_{ij}}{365} \right)^2 \right]} \tag{22}$$

3. Include order frequency for those distribution centers ordering in weekly periods

$$\sigma_{iz} = M * \sqrt{\left(W_{iz} + 7\right) \sum_{j=1}^{11} \left(H_{ij} * s_{ij}^2\right) + \left(V_{iz}\right)^2 * \sum_{j=1}^{11} \left[H_{ij} * \left(\frac{D_{ij}}{365} \right)^2 \right]} \tag{23}$$

σ_{zj} **(hub outbound)**

1. Calculate standard deviation of demand over the lead time

$$\sigma_{zj} = \sqrt{W_{zj} * \sum_{i=1}^{3} (H_{ij} * s_{ij}^2)} \tag{24}$$

2. Include variance of the lead time

$$\sigma_{zj} = \sqrt{W_{zj} * \sum_{i=1}^{3} (H_{ij} * s_{ij}^2) + \left(\frac{\sum_{i=1}^{3} (H_{ij} * D_{ij})}{365} \right)^2 * (V_{zj})^2} \tag{25}$$

3. Include order frequency for those distribution centers ordering in weekly periods

$$\sigma_{zj} = \sqrt{(W_{zj} + 7) * \sum_{i=1}^{3} (H_{ij} * s_{ij}^2) + \left(\frac{\sum_{i=1}^{3} (H_{ij} * D_{ij})}{365} \right)^2 * (V_{zj})^2} \tag{26}$$

4. Include share of variance of forecast errors over the variable lead time to the hub (approximation of Eppen and Schrage (1981) formula)

$$\sigma_{zj} = \sqrt{(W_{zj} + 7) * \sum_{i=1}^{3} (H_{ij} * s_{ij}^2) + \left(\frac{\sum_{i=1}^{3} (H_{ij} * D_{ij})}{365} \right)^2 * (V_{zj})^2 + (1 - M) * \left[\sum_{i=1}^{3} \left(\frac{H_{ij} * \sigma_{ij}^2 * W_{iz}}{\sum_{j=1}^{j=11} H_{ij}} \right) + \sum_{i=1}^{3} \left(\frac{H_{ij} * \frac{D_{ij}}{365} * (V_{iz})^2}{\sum_{j=1}^{j=11} H_{ij}} \right) \right]} \tag{27}$$

The next step will be to find the values of k that will satisfy a specified fill rate. We used the common procedure of finding the k that meets the following criteria:

$$G_u(k) = \frac{Q}{\sigma} * (1 - E) \tag{28}$$

We can look up the k for a given $G_u(k)$ in tables from Silver, Pyke and Peterson (1998). However, as this reference points out, “This equation underestimates the true fill rate if σ is large relative to Q, because it double-counts backorders from a previous cycle that are not met at the start of the next cycle." The supply chain channels we are modeling are frequently characterized by long, variable lead times. Container shipment quantities are often small with respect to the variance of forecast errors during such ample lead times. This means that if we only use the above criteria, our model will frequently suggest a higher safety stock than is really necessary to provide a specified fill rate. To correct this issue, Silver, Pyke and Peterson (1998) suggest the following corrected criteria for finding a k:

$$G(k) - G(k + \frac{Q}{\sigma}) = \frac{Q}{\sigma} * (1 - E) \tag{29}$$

According to the suggestion in Silver (1970), we implemented this correction for cases where $\frac{\sigma}{Q} \geq 2$, while maintaining the standard method for the rest of the cases.

4.7 Calibrating the Model

To evaluate the model's accuracy at predicting inventory levels, we compared the estimated inventory in a baseline scenario of the model, where all products are shipped direct, with the actual average inventory levels of the past two years. To model the baseline scenario we simply set all binary decision variables as 0. This leads to all distribution centers receiving their product directly from the factories and nothing flowing through the hub. With these settings we recreated the current situation and obtained the following results:

DC	Avg. Actual Stock (Pallets)	Avg. Theoretical Stock (pallets)	Avg. Actual Days On Hand	Avg. Theoretical Days on Hand
GUATEMALA	795.1	241.6	103.5	31.4
EL SALVADOR	774.5	270.8	106.6	37.3
HONDURAS	674.0	168.0	131.1	32.7
NICARAGUA	579.6	272.0	91.3	42.9
COSTA RICA	1,015.6	346.1	92.0	31.4
PANAMA	751.3	152.7	182.6	37.1
BOLIVIA	521.9	347.2	41.3	27.5
COLOMBIA	2,523.2	1,481.6	65.1	38.3
ECUADOR	1,396.1	598.2	67.0	28.7
PERU	990.8	665.4	67.2	45.2
VENEZUELA	3,750.7	1,588.4	63.7	27.0
TOTAL	13,772.8	6,132.0		

Table 10: Comparison of Actual Stocks and Baseline Theoretical Stocks

Consumer Co. does not include pipeline inventory in their data, so the figures for the theoretical stock do not include this amount. Actual stock was much higher than theoretical stock. According to Consumer Co., the difference can be attributed to overstock in the current supply chain due to new product overstock, bias in the forecast, promotional product inventory policies, and obsolescence. These are factors which were out of the scope of the model and unlikely to affect the hub decision.

New product behavior is believed to be the main reason for overstock in Consumer Co. Approximately 18% of the company's volume is generated by innovations, which are either extensions of current product lines or completely new products. For every launch, the company has the policy of initially shipping enough pallets to cover the first six or seven weeks of estimated demand and then proceeding with a monthly replenishment cycle. This continues until the product is no longer considered new three months after launch. Forecast accuracy is estimated to be 24%

lower in this life-cycle phase and therefore the ordering policy, combined with the long lead times of the supply chain, often results in considerable overstock of new products.

Another reason for overstock is that country sales managers occasionally override the forecast calculated by the Planning Department with an overly optimistic figure. They do this in order to improve their odds of meeting their sales quotas. Not surprisingly, this *biased* behavior often leads to excessive build ups of inventory at the distribution centers. Theoretically, objective forecasts produce random errors which in the long run cancel each other out and add up to zero. A biased forecast can be detected when errors are consistently above or consistently below the actual demand. The following chart is an example of the amount of bias that a sales manager for Consumer Co. inserted into the forecast.

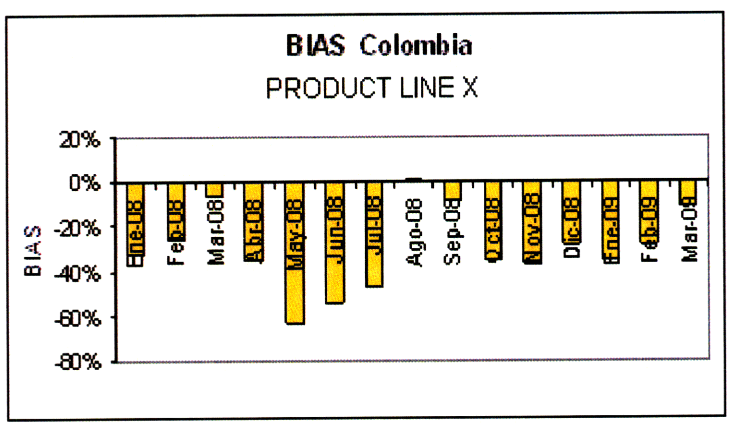

Figure 5: Example of consistent bias in the forecast

Additional reasons include low promotional forecast accuracy and product obsolescence. Due to limited time and resources, it is not possible for Consumer Co. to filter all of these factors out of the actual data to compare with the simulated inventory. Another solution to have a better comparison would be to include these factors in the model. This is something that was out of the scope of this project, but is a good opportunity for further research.

4 Solution Analysis

Results

Our evaluation focused on the total landed cost savings that could be achieved by introducing a distribution hub in Consumer Co.'s import supply chain. We analyzed scenarios with the hub location being either in Panama or Colombia. A systematic search of the different model scenarios revealed that there could be 4.4% savings from adding distribution hub capability in the Colon Free Trade Zone in Panama for Consumer Co.'s NWLA supply chain.

Decision Variables: Best Result		
HUB SAFETY STOCK		1
GUATEMALA	ARGENTINA	0
	BRASIL	0
	MEXICO	0
EL SALVADOR	ARGENTINA	0
	BRASIL	0
	MEXICO	0
HONDURAS	ARGENTINA	0
	BRASIL	0
	MEXICO	0
NICARAGUA	ARGENTINA	0
	BRASIL	0
	MEXICO	0
COSTA RICA	ARGENTINA	1
	BRASIL	0
	MEXICO	1
BOLIVIA	ARGENTINA	0
	BRASIL	0
	MEXICO	1
COLOMBIA	ARGENTINA	0
	BRASIL	0
	MEXICO	0
ECUADOR	ARGENTINA	0
	BRASIL	0
	MEXICO	0
PERU	ARGENTINA	0
	BRASIL	0
	MEXICO	0
VENEZUELA	ARGENTINA	1
	BRASIL	1
	MEXICO	1

Table 11: Decision Variable Configuration for Best Result

Solution	Shipping	Holding	Hub Handling	Total Cost	Savings	%
Baseline	$ 14,589,610	$ 3,554,840	$ -	$ 18,144,450		
Hybrid Panama	$ 13,622,719	$ 2,977,499	$ 752,129	$ 17,352,348	$ 792,102	4.4%
Total Hub Panama	$ 16,662,031	$ 3,007,528	$ 1,996,147	$ 21,665,706	$ (3,521,256)	-19.4%
Total Hub Colombia	$ 23,150,137	$ 4,229,727	$ 1,088,720	$ 28,468,584	$ (10,324,135)	-56.9%

Table 12: Predicted Costs for the Different Alternative Solutions

Savings are realized with a "Hybrid" solution, where the hub would service only certain source-destination nodes, indicated in Table 11, and the rest would be sourced directly by the production countries. The hub would not operate as a cross dock, but would also hold safety stock in order to provide added benefits. Although the products shipped through the hub would travel increased distances, savings would be provided by a reduction in shipping and holding costs. These are primarily achieved with the risk pooling of forecast error over the production lead time, lower duties paid on shipping costs, and reduced transportation rates going into and out of Panama. The "Total Hub" solution, where all products flow through the hub operated at a 19.4% higher cost than the baseline.

In the "Cross dock" scenario, where no safety stock is held at the Panama hub, we also found savings, but they were not as large as the savings when safety stock was incorporated at the hub. As with the hub holding inventory, only certain source-destination combinations provided positive returns. This reduced savings as compared to the scenario of inventory holding at the hub is driven by the regional distribution centers not realizing as much savings from inventory reduction.

The cost of shipping, which accounts for 81% of the total actual cost, has a considerable influence on the model's final solution. We estimated the annual miles shipped using a straight-line and adding a 20% circuity factor. We then divided the total shipping cost by this number to obtain the cost per mile.

Solution	Shipping	Miles	$/mile
Baseline	$ 14,589,610	7,543,419	$ 1.93
Hybrid Panama	$ 13,622,719	8,313,260	$ 1.64
Total Hub Panama	$ 16,662,031	9,773,308	$ 1.70
Total Hub Colombia	$ 23,150,137	9,124,110	$ 2.54

Table 13: Transportation Analysis

The revelation of these figures is that by shipping to Panama and then to the final destination there is a lower cost per mile and in some cases lower total shipping costs than by shipping direct. This can be explained by the economies of scale available in ocean shipments to and from Panama. Given the country's unique geographical structure, there is considerable volume of traffic flowing through these lanes. Panama also stimulates volume growth by applying low duties and tariffs, access to Free Trade Zones and efficient customs clearance times. Panama's port infrastructure ranked 15th in the 2008-2009 Global Competitiveness Index. Direct shipping lanes like Mexico- Bolivia, Brazil-Nicaragua or Argentina-Guatemala lose their shorter distance advantage because these links have a higher cost per mile. A higher cost per mile increases the gap between the baseline and the hybrid solution providing even more savings.

An alternative hub location that we wanted to evaluate was the current Colombia RDC. Since Colombia accounted for 21% of total demand and enjoyed a closer proximity to Venezuela, which accounted for 31%. We assumed that having the hub operate from the Colombia RDC would likely reduce the total distance traveled. After testing this scenario, we found out that this assumption was true, but the higher cost per mile and longer lead times drastically increased shipping and holding costs. The total cost for a completely centralized hub in Colombia was $10.3 million greater than for the baseline scenario. As can be seen in the following table, the shipping costs and lead times to and from Colombia are considerably higher than Panama's. Cost per mile was 31% greater than in the baseline and 55% greater than in the Hybrid Panama hub. In the end, we could not find a feasible solution for any scenario with a hub in Colombia.

		TOTAL HUB COLOMBIA		TOTAL HUB PANAMA	
		Cost/Container	LT	Cost/Container	LT
FROM	ARGENTINA	$ 4,308	39	$ 2,799	35
	BRAZIL	$ 5,585	39	$ 2,849	36
	MEXICO	$ 3,913	23	$ 1,863	17
TO	GUATEMALA	$ 3,221	35	$ 3,337	7
	EL SALVADOR	$ 4,391	35	$ 2,943	6
	HONDURAS	$ 6,121	35	$ 3,793	6
	NICARAGUA	$ 3,301	35	$ 2,491	5
	COSTA RICA	$ 4,240	48	$ 1,768	4
	BOLIVIA	$ 3,976	31	$ 4,168	18
	ECUADOR	$ 4,359	23	$ 4,081	15
	PERU	$ 3,572	24	$ 3,301	18
	VENEZUELA	$ 6,899	38	$ 5,615	26

Table 14: Comparison of Colombia and Panama Hub Shipping Costs

Higher shipping costs and lead times into and out of Colombia can be attributed to a lack of infrastructure. The presence of the Andes Mountains and rainforests makes the construction of roads and railroads more expensive and truck fuel efficiency lower. Just as Panama, Colombia has access to the Pacific and Atlantic Oceans. However, its port infrastructure is not as effective as Panama's. Colombia ranks consistently lower than Panama in the World Economic Forum's Global Competitive Index for categories relevant to our case. All of this is reflected in higher shipping costs and lead times, making Colombia an infeasible location for a hub in Consumer Co.'s NWLA import supply chain.

	Roads	Ports	Overall Infrastructure
PANAMA	57	15	54
COLOMBIA	91	108	84

Table 15: 2008 GCI Ranking

Sensitivity Analysis

With so many dynamic variables in the analysis, it is important to test the sensitivity to fluctuations in each. The sensitivity analysis that we conducted involved running optimizations altering each input variable to -20%, -10%, +10%, and +20% of its current actual value and measuring the savings projected by our model. Our analysis pointed to five key variables which when increased lead to increased savings from implementation of an international distribution hub. The variables that were observed to increase savings from implementing a hub were average yearly demand, monthly MAPE, cost per mile, fill rate, average lead time and carrying charge. An increase in hub handling cost has the opposite effect on total savings.

The following table details the percent savings change from baseline provided by a Panama hub as each variable was analyzed at -20%, -10%, 10%, and 20% of the baseline value. As can be seen in the table, the sensitivity of the savings is very dependent on the variables.

Variable Change	-20%	-10%	10%	20%
Avg. Yearly Demand	-20%	-10%	10%	20%
Monthly MAPE	3%	6%	2%	4%
Fill Rate	-33%	-18%	27%	86%
Avg. Lead Time	-46%	-23%	24%	50%
Carrying Charge	-15%	-7%	7%	15%
Hub Handling Cost	27%	12%	-12%	-26%

Table 16: % increases in savings for different % increases in key decision variables

As the yearly demand was tested, the total savings provided by a distribution hub in Panama moved in equal percentage increments. This analysis shows that the volume on demand for Consumer Co. imports increases the savings provided by the hub increase equally. As Consumer Co. assesses the future growth plans of their business, it is important to know that demand and total savings move in sync.

The variables for which savings were most sensitive were fill rate and lead time. Slight changes to these variables resulted in increased savings of up to 86% from the baseline. This can be explained by the fact that these two variables are key components of safety stock. Safety stock increases exponentially as service level approximates 100% and also increases when lead time increases. As safety stock becomes a larger part of the inventory, the risk pooling benefits of centralizing inventory are considerably increased.

Conclusions

Companies sometimes must invest heavily in safety stock because of long lead times, low forecast accuracy or high service level requirements. These are great opportunities for savings if companies can find creative ways to centralize inventory in the proper situations. Increased transportation costs may or may not be compensated by reductions in holding costs. Companies must assess correctly which links in their supply chain may benefit from centralization. A correct strategy can provide improved service level at the same cost resulting in increasing profits.

Another key takeaway is that carriers can sometimes offer lower rates for shipping containers indirectly through a high traffic point instead of shipping the product directly through a less traveled route. This is similar to airlines offering lower fares for indirect flights flying through hubs due to the achievement of higher utilization rates and economies of scale. Consumer Co. can generate savings simply by cross-docking some of its more expensive shipping lanes through the Colon Free Trade Zone for a "layover" and then shipping to the final destination country.

Hub capability in the Colon Free Trade Zone provides Consumer Co. with the flexibility to tailor their supply chain to potential changes in the environment. Latin America is an emerging market with fluctuating conditions still in development. Demand, interest rates, inflation, duties, and infrastructure are all variables which can by no means be considered constant in this region. Consumer Co. could also possibly implement a hub of its own after gaining experience with the 3PL. This would reduce handling costs and fees, which would lead to greater profits if the hub ever increases its scope. There is also the matter of competition leading to constantly increasing customer expectations and desired fill rates. As seen in our sensitivity analysis, required safety stock levels increase exponentially as service level goals increase, which results in greater savings from centralization. The spreadsheet model we have developed for Consumer Co. can be a useful tool for them to evaluate the best hub network design for different scenarios in their NWLA region and in other regions around the world which they service with imported products.

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