Logistics: Shipment Problem

Logistics Final Project

Group 2: Nick Morris,
Milwinda Castillo, &
Amanda Johnson

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Current State:

It is always important to look to the future and plan ahead. Even if reality does not end up matching your predictions, the planning process creates, at the very least, a default from which you can vary your actions to respond to various problems that may arise. Understanding this, we must develop a plan with which a shipping company will handle the transportation of shipments and the containers that will hold them between three ports: A, B, C. The shipping company has a limited number of boats-- 2 large ones, 3 medium sized ones, and 4 small ones --so it is important to set the route of each boat such that each port is served and receives shipments from both of the other ports.

Once the routes of the boats are determined, containment for the shipments must also be handled. The company is able to use three sorts of containers: 40 ft, 40 ft Collapsible, and 20 ft. The contents of two 20 ft containers would fit into one 40 ft container, be it regular or collapsible. Each port can sell or lease containers to the shipping company, but there is a limit to how many containers will be available and a lead time associated with this as the containers must be brought to the port by train. About 80% of the containers used by customers will be returned to their respective port within three weeks of their arrival. Empty containers can also be shipped from port to port or sold at the port if they are not needed. In the end, we must create a plan for 26 weeks which will indicate the routes each boat will travel, the amount of empty and full containers it will carry on each trip and the number and kind of containers which will be bought, leased, or sold at each port.

Tactical Plan:

The Route and Ports for each Boat:

The approach used to evaluate which boat should follow a particular route was a combination of a discrete event simulation and an experimental design. A discrete event simulation method was chosen because it would incorporate the stochastic nature of the random normal travel times between ports. The simulation software used was Simio 7 and the structure of the model was built with the intention of simplicity and speed for ease of experimenting.

The simplicity was achieved by representing each port with three objects. The first two objects were two sources that would create containers, which arrived in quantities and at time intervals consistent with the forecasted demand given. The reason each port had two sources, was to separate containers that were intended to supply the other two ports. The third object was a sink which would consume and remove containers from the system, to represent satisfied demand at the particular port. The simplicity was also achieved by ignoring all costs because the focus of the simulation was service level. The containers used were only 20 foot containers to directly relate to the forecast numbers. Containers were supplied at ports through purchasing, and never recycled back into the system by consumers. This allowed for the right quantity of containers to be placed at the right port at the right time for the right destination. Overall the simplicity of the model let supply and cost to not constrain the performance of the routing sequences and their resulting service levels.

The speed of the model was achieved by scaling the timeline of the problem such that 1 day was represented by 1 minute. This was done to minimize the information that the software had to record, and therefore output results faster. The speed was also achieved by dividing the forecast numbers and boat capacities by ten. This scaling was done to decrease the number of entities in the system throughout the run time, and again reduce the amount of information that the software had to track and record. Overall the speed of the model allowed for the large experimental design to be tested without pressuring the timeline of this project.

The experimental design chosen was a 15^9 factorial design. The 15 levels consisted of two adjacent routes, two orbiting routes, and one pivoting route, for each of the three ports that a boat could start at. The total possible combinations were massive, so these combinations were represented by four samples, each with 1000 combinations for a total of 4000 routing sequences to evaluate. The first sample consisted of routing combinations with just adjacent routes, and these were randomly selected. The second sample consisted of routing combinations with just orbiting routes, and these were randomly selected. The third sample consisted of routing combinations with just pivoting routes, and these were randomly selected. The fourth sample consisted of routing combinations with any route, and these were randomly selected. The 4000 runs were not replicated, and were all evaluated in one large experiment by Simio 7. The top ten runs were chosen by highest overall service level for the system, and then were used to determine departure times of each boat.

The Departure of each Boat:

The top ten results of the routing simulation experiment allowed for the route and starting port of each boat to be known. The results also happened to only include adjacent routes for each boat. The next step was to improve the service level results by determining when each boat should depart. In the routing experiment, each boat departed from a port in time to satisfy the first week's forecasted demand of their intended destination. The top ten results showed multiple boats following the same route sequence, starting at the same port. This creates under-utilized boats for the first half of the simulation until backlogged orders built up at ports. This under-utilization of boats was evident because the arrival of containers at ports are linked to the forecasted demand which is significantly lower than boat capacity week-to-week. Therefore the next experimental design was intended to determine when a boat, that shares the same route as another boat, should depart to increase the overall service level of the system.

The experimental design chosen, for each of the ten routes, was a 3^k factorial experiment where 'k' represents the boats that shares the same route and start as another, and can vary by departure. The 3 levels chosen were departing 'On-time', 'One Week Late', and 'Two Weeks Late'. It is important to note that in a set of boats which share the same routing, one boat with the largest capacity must leave on-time so that the first week's demand for their intended destination is met. The experiments run in Simio 7 were nine 3^5 factorials and one 3^6 factorial. The best result for each experiment based on overall service level was chosen, and then out of those ten chosen, the top five based on overall service level were ultimately chosen for further evaluation.

Each of these five routings were represented in a timeline table. This table was set up to show where each boat is expected to be during each week, either at a port or between two ports heading towards one port. This table was developed to allow for a container purchasing schedule, and boat fill rate schedule to be created because the direction, position, and capacity of each boat during each week is now fixed. Ultimately, the final routing and departure for each boat that was chosen is given in Table 3 of the appendix.

Operational Plan:

Design of the Shipping Service:

The objective in this stage is to minimize the total cost incurred during the planning of resources to fulfill the demand of containers at each port. In order to achieve this, a decision making process was designed, in which the decision-maker will obtain feasible results.

The total cost is the summatory in the 26 week planning period of the inventory cost incurred at each port, set-up cost at each port, the positioning cost of exporting and importing containers, purchase cost, and leasing cost minus any earnings obtained from selling containers.

The following section describes the methodology used to determine the container planning for the shipping company. Appendix I describes the proposed assumptions and the description of the formulas used.

Decision Making Process:

The steps proposed can be described as followed:

1. Identify the consumer, producer, and balanced ports.
2. Assign the empty containers to fulfill the demand based on the number of available empty containers.
    a. The procedure of this step is depicted in greater detail in Figure 1 of the appendix.
3. Do step 2 for each of the ports in a given period.
4. Position empty containers in a given period for Producer/Consumer ports.
    a. The procedure of this step is depicted in greater detail in Figure 2 of the appendix.
5. Do step 2 through step 4 for all the periods.

Results:

Computational Results:

*T*he results obtained from the tactical and operational plans are as followed. The formulas were implemented in an EXCEL 2013 spreadsheet. Table 1 shows the operational plan for the chosen route, Route 2. This table describes the different capacities for laden and empty container loaded in each boat per trip. Notice that, for the balanced ports (A-B) the boats are usually fully loaded with laden containers in each trip, meanwhile for the producer/consumer ports (A-C, B-C), it is different. This is due to the producer ports usually send fully loaded boats with laden containers but the consumers usually use 50 % of the boat capacity to send laden container and the rest to reposition the surplus of empty containers. It is important to note that some boat routes may present under-used capacity for the boat, which means that the routes and fleet assignments could be improved.

Table 1. Boat Fill Rate Plan

Capacity	500		500		1000 (500 x2)				1200		1200		750		750		750	
Route 2	boat 1		boat 2		boat 3		boat 4		boat 5		boat 6		boat8		boat 7		boat 9	
Route:	C_A	A_C	B_A	A_B	C_A	A_C	C_A	A_C	C_B	B_C	C_B	B_C	C_B	B_C	A_B	B_A	A_B	B_A
Full Loaded	100%	100%	100%	~100%	~50%	100%	~50%	100%	~ 50%	100%	~ 50%	100%	~ 50%	~50% - 100%	~70%	~70%	~35%	~35%
Empty					~50%		~50%							~50 - 100%				

Using this method with Route 2, it achieved an 85% service level with approximately a total cost of $45,700,000. The high value of the total cost was incurred due to the fact that in order to achieve a good service level and fulfill the demand of containers, the shipping company must invest a large quantity of money in container purchases. Table 2 presents the details of the demand fulfilled and Table 2 below presents the list of cost generated.

Table 2. Cost Breakdown at an 85% Service Level

Cost	Value
Inventory	$12,687,325.00
Purchase	$21,284,400.00
Positioning	$8,410,306.00
Set up	$3,315,000.00
Total cost	$45,697,031.00

Additionally, the company must take into consideration the purchasing and leasing plan. In order to have the newly or leased containers available on time, orders must be planned ahead to account for the lead time period. Table 5 gives the results for the purchasing activities plan and delivery schedule. Notice that there is a large amount of orders requested at port A and B, this is because they're producers and need to purchase containers to fulfill demand when repositioning empty containers is not sufficient. Also, the containers purchased were 40ft regular which are the least expensive. None of the other containers were leased or sold either because it was not cost-effective under our conditions in the system.

Concerns:

Limitations - Tactical Plan:

The concerns regarding the tactical plan of our solution begin with the insignificant proportion of routes evaluated in the 15^9 factorial experiment. Routes that weren't evaluated may have resulted in service levels slightly larger than the top ten routes that were chosen. Additionally, if different routes were evaluated, the overall solution could have been more cost-effective. Despite the proportion, the results of 4000 routes chosen were promising as shown in Figures 3 - 6 in the appendix. These figures show that there is a distinct upper tail in the distribution of service levels for each figure, except for Figure 3 which approaches a 100% service level. These upper tails indicate that the upper limit of service level has likely been identified, and any further combinations evaluated may only return marginal improvement compared to the top ten chosen.

The next concern is that the departure levels chosen for the boat departure experiment may have limited improvement. The improvement in overall service level for each of the top ten routes were as large as approximately 2%. This shows that varying departure may yield insignificant improvement, or valuable departure waiting times greater than two weeks, should have been evaluated.

Another concern is that the probabilistic nature of consumers returning containers into the system was ignored in the simulation model that would have been capable of capturing this effect. The final concern with the tactical plan was that costs were ignored in order to simplify the simulation model. If this project was to be reevaluated, this is an area of improvement because there may have been some routes with slightly lower service levels than the top ten chosen, but with significantly lower expected costs requirements.

Limitations - Operational Plan:

The concerns regarding the operational plan of our solution first include that safety stock for the empty containers were not considered in the solution development process. Despite that there was no information on the accuracy of the forecasted demand, it may not be correct. Therefore, including a safety stock for empty containers in the solution would have been beneficial to deal with the variation that exists in the system day-to-day.

Another concern is that backorder costs were not a factor when determining the most cost-effective container purchasing and boat fill rate schedules. If backorder costs were considered, it may yield a solution that is more cost effect than our proposed solution.

The next concern is the manual computation required in Excel to determine the purchasing and boat fill rate schedules for the operational plan. An area of improvement that would be taken advantage of if this project was to be reevaluated, is developing an automated process in Excel with better formulas and/or macros. This would allow for the decision-making process developed in the operational plan to be implemented such that it provides swift and consistent results.

The next area of improvement that would be addressed if this project was to be reevaluated, is an (m, n) policy for each port to determine when empty containers should be imported and exported. This policy would operate such that empty containers are imported up to 'm' quantity when the number of empty containers is less than 'm' quantity. Additionally, empty containers should be exported down to 'n' quantity when the number of empty containers is larger than 'n' quantity.

Additional Considerations: Collapsible Containers

Collapsible containers are a relatively recent innovation. As one might expect because of the name, the containers collapse when they are empty. They allow more empty containers to be shipped at once and which can be stored far more compactly. A collapsible container uses a quarter of the space that a regular forty foot container requires and can be stored and held at ports, on average, for a fifth of the cost of normal containers. They are also far easier to store at port, making the ports' jobs simpler as far as holding empty containers is concerned. To reflect that ease, the cost to store a collapsible container at a port is, on average, a fifth of the cost to store a regular 40 ft container. Unfortunately, making and moving a collapsible container is more complicated, so the cost to buy a collapsible container is very high, $1200 more than the cost of a regular 40 ft container (you could buy an entire 20 ft container and still have $100 left over afterward), and the costs to move them around are usually about $30 more expensive per container than for regular 40 ft containers. Knowing this, one has to determine: who benefits from the collapsible containers and when does it make most sense for the shipping company to use them?

Collapsible containers are effective in two situations: when shipping containers and when holding containers. When shipping containers, collapsible containers save space so you can send 4 times as many containers from one port to another without paying setup for more than one boat. Because of the increased cost of buying a collapsible container and moving these containers, there comes a point when the cost of the containers outweighs the savings of needing fewer boats (See Table 6 in the Appendix for details). The number of collapsible containers that it is worth shipping is rarely very high and, even as regular containers, will never fill even one boat much less necessitate an additional shipment. What collapsible containers offer then, is the ability to stuff more containers onto a boat which is also carrying a large load of filled containers for delivery. This means it is possible to satisfy demand for empty containers in situations where it might otherwise not be possible.

Collapsible containers also offer the ability to store empty containers in a more reasonable amount of space at port, making their storage less demanding on the people running the port. For this reason, they charge less to store them. The savings are significant, but the initial price is far more so. If you were to compare the cost difference to the savings in storage costs, it would take about 22 weeks of sitting in port A, 10 weeks at port B, or 17 weeks at port C to make up the difference for a single container. Considering that we plan only 26 weeks at a time, these payback periods are too long. Reducing the initial cost to reduce the payback periods would make the collapsible containers a much more reasonable investment. As containers would only have to be paid back once to make the initial cost worthwhile, the average maximum wait time among the ports provides a better payback period for which to aim. That period is about 11 weeks. Using this and the savings at each port, it was possible to determine the price difference which would be acceptable on average. This turns out to be a price drop of only $275. This price reduction also reduces the difference between the initial and salvage prices for the collapsible containers from $1000 to $775. This is still almost double the difference for the regular 40 ft containers, $400, but this is a digestible risk if the payback period of the price difference is lower. If there were a way for the shipping company to spend a little less initially, the collapsible containers would become a good purchase.

It is to the ports' benefit if the shipping companies use more collapsible containers as empty containers will not stack up so high at the port and they will require fewer shipments to be rid of if the port decides to send them away. As the port benefits, maybe we could achieve that lowered price by having the ports pay shipping companies to buy collapsible containers. Another idea is that they could make shipping empty collapsible containers more reasonable by reducing the price to handle empty collapsible containers. Perhaps they could find a way to wrap the four collapsible containers so that moving a stack of four is exactly like moving a single regular 40 ft. Then, they could offer a move one, move three free deal which would make collapsible containers far cheaper to move than they currently are.

Collapsible containers can also benefit shipping companies. Perhaps more research could be done into the possibility of purchasing a fleet of smaller, faster boats to transfer the containers from port to port. These would shorten the lead times to bring the empty containers from one port to another, making this option more reasonable in comparison to purchasing new containers. Depending on how much faster these smaller boats managed to be, they might even make the number of containers which need to be in the system at any one time smaller, bringing our costs down. In any case, the collapsible containers merit more negotiation as far as pricing or incentives from the port and some further consideration of how to work them into this system.

Appendix :

***Table 3:** Chosen Boat Routing and Departures*

	Boat 1	Boat 2	Boat 3	Boat 4	Boat 5	Boat 6	Boat 7	Boat 8	Boat 9
Route:	C_A	B_A	C_A	C_A	C_B	C_B	A_B	C_B	A_B
Port Start:	C	B	C	C	C	C	A	C	A
Depart:	-5	-3	-4	-4	-7	-7	-3	-7	-1
Capacity:	500	500	500	500	1200	1200	750	750	750

I. Project Assumptions and Formulations

Project Assumptions:

1. ***E**ach port has enough container to satisfy the first shipment.*
2. The average estimated length of stay per container at each port is 1 week
3. Just 80% of the container will return empty from the customer after 3 weeks of arrival. The other 20% will disappear from the system.
   $\mathbf{Returned_{kpt} = 80\%\ Shipped\_Full_{kpt-3}}$
4. No lost sales allowed (Everything should be intended to be shipped)
5. Condition under which would be more cost effective:
   - *Buy or lease:* Lease, if the leasing cost * number of weeks keep it in stock is less than purchase cost. Otherwise, buy.
   - *Sell:* Sell, if the sum of the total holding cost of the owned container is greater than the expected reimbursement (Purchase cost - selling price).Otherwise, do not buy.
6. Preferences: This describes the suggestions to assign container to a boat base on the expected cost of the operation and related activities.
   - Assignment: 40ft Regular, 40ft Collapsible, 20ft Regular.
   - Buying and leasing: 40ft Regular, 40ft Collapsible, 20ft Regular.
   - Repositioning: Owned 40ft Collapsible, 40ft Regular, 20ft Regular.
7. If a boat reaches a port within a given week, then the outstanding demand at that port for that week is satisfied with the boat's capacity of full containers.

Notations:

- k - set of containers
- t - set of periods
- p - set of ports
- b - set of boats

Parameters

- d_{kpt} -demand of containers from port i to j
- CB_b - Capacity of the boats
- $Max\_newlyContainer_{kp}$
- I_{kp0} - Available container at the beginning of the process
- $Returned_{kpt}$ - Returned empty container k in port p in t **(See assumptions)*
- B_cost_{kp} - Purchase cost
- L_cost_{kp} - lease cost
- S_price_{kp} - sell price
- P_cost_{kp} - Positioning cost
- H_cost_{kp} - Holding cost
- SU_cost_{kp} - SetUp_cost
- $Boat_t$ - Binary: 1 if boat depart at t. Otherwise 0.

Decision variable

- $Shipped\_Full_{kpt}$
- $Shipped\_Empty_{kpt}$
- $Bought_{kpt}$
- $Leased_{kpt}$
- $Sold_{kpt}$

In which the following formulas were used:

- ***Available_Container***$_{kpt}$ = $Inventory_{kpt}$ = I_{t-1} + $Returned_{kpt}$ + $Repositioned_{kpt}$+Bought(Received) $_{kpt}$ + Leased(Received) $_{kpt}$ - Sold $_{kpt}$ -Shipped $_{kpt\ (Full/Empty)}$
- ***Returned***$_{kpt}$ = 80% Shipped_Full $_{kpt\ -3}$
- ***Total_demand (t+1) =*** $Expected\_Demand_{kpt+1}$ $=Forecasted\_Demand_t$
- ***(AR)Available_Container***$_{kpt+1}$= $Available\_Container_{kpt}$ + $Returned_{kpt}$ - $Expected\_Demand_{kpt+1}$
- ***Total_sells=*** sum(k,p,t)**Sold** $_{kpt}$ ***S_price**$_{kp}$
- ***Total_lease_cost =*** sum(k,p,t) **Leased** $_{kpt}$***L_cost**$_{kp}$
- ***Total_Purcharse_cost =*** sum(k,p,t)**Bought** $_{kpt}$***B_cost**$_{kp}$
- ***Total_Inventory_cost=*** sum(k,p,t)**Inventory**$_{kpt}$ ***H_cost**$_{kp}$
- ***Total_SetUp_cost=*** sum(k,p,t) **Boat**$_t$ ***SU_cost**$_{kp}$
- ***Total_positioning_cost=*** sum(k,p,t) (**Shipped_Full** $_{kpt}$ **+ Shipped_Empty** $_{kpt}$**) *P_cost**$_{kp}$
- ***Total_Cost=*** TotalInventory_cost + TotalSetUp_cost + Totalpositioning_cost - Totallease_cost - TotalPurcharse_cost - Total_sells.

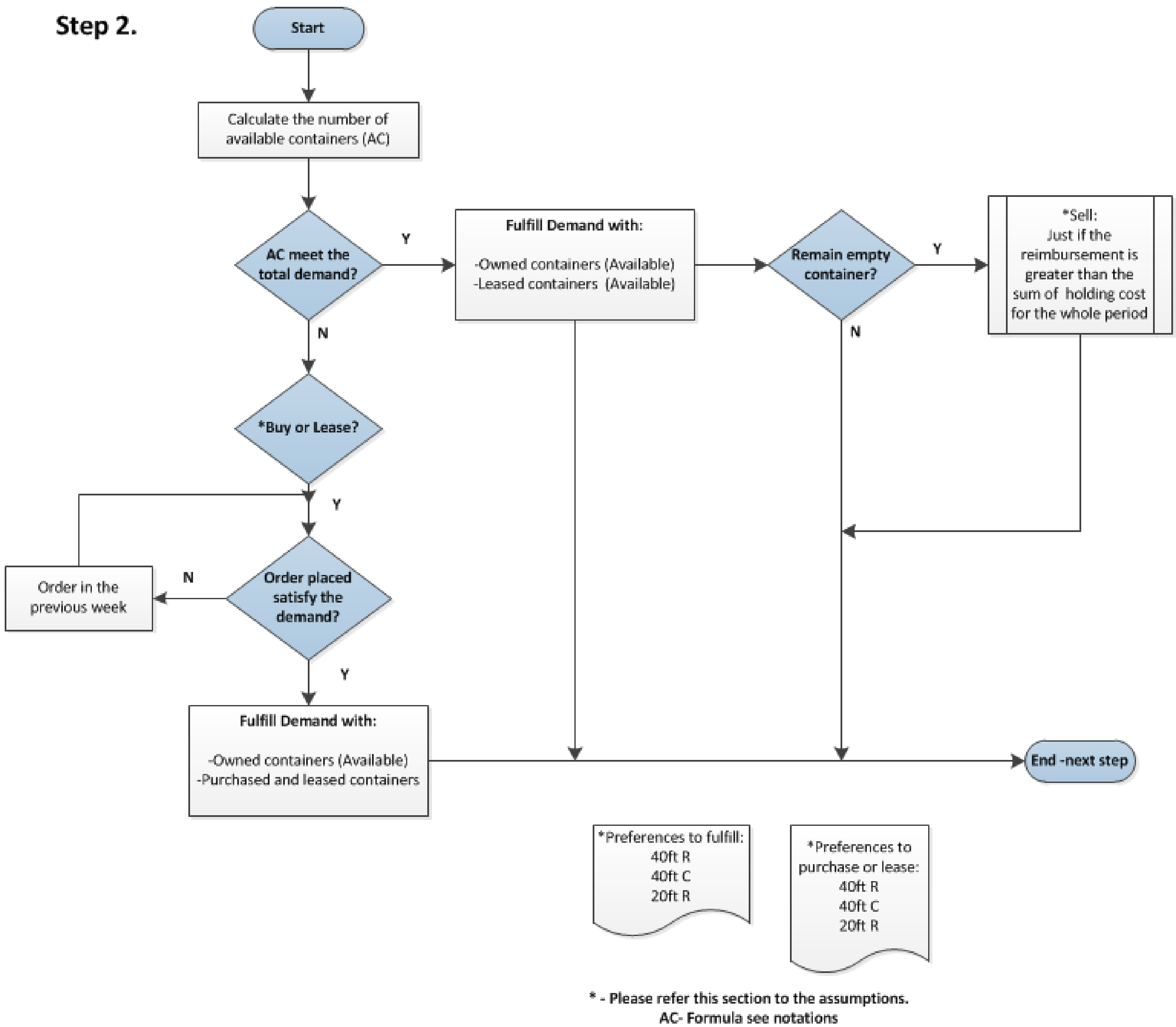


Figure 1: Step 2. Represents the Flow for the Empty Container Assignment to Fulfill the Demand

Step 4.

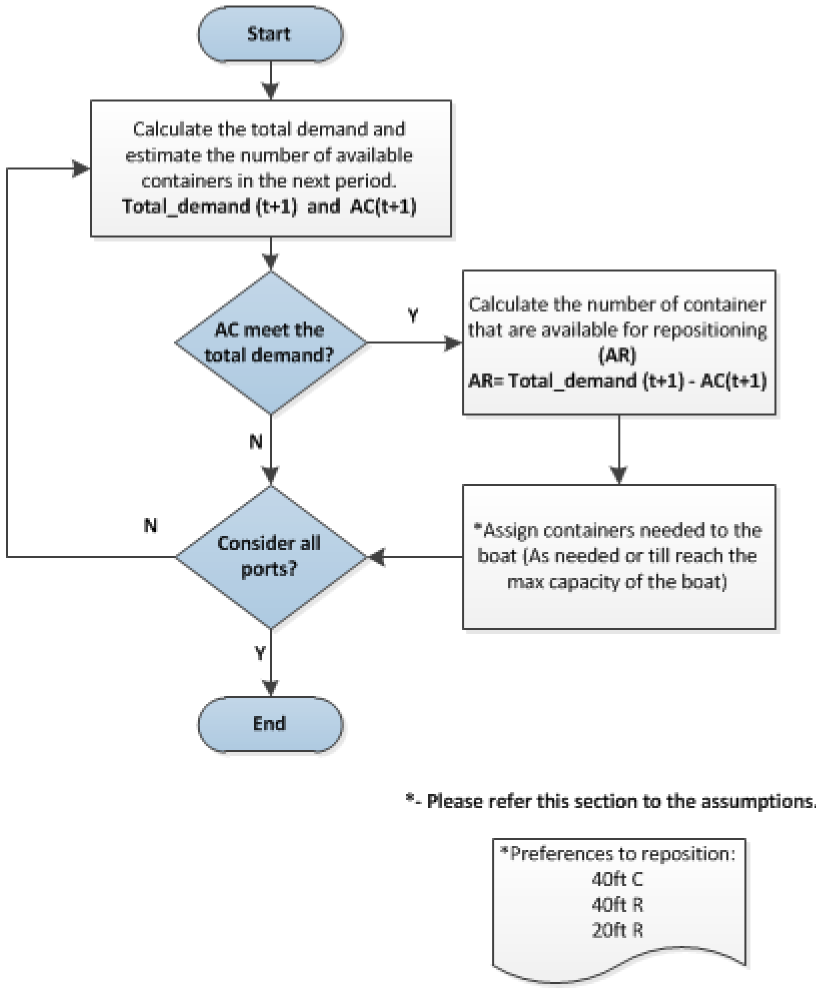


Figure 2: Step 4. Represents the flow for the reposition of empty container

Table 4. Shows the detailed service level achieved for each port.

Origin	Destination	Expected Aggregated demand	Shipped	Satisfaction
A	B	5235	5235	**100.00%**
	C	7328	7093	**96.79%**
B	A	4098	4098	**100.00%**
	C	10924	6300	**57.67%**
C	A	2018	2018	**100.00%**
	B	2823	2823	**100.00%**
		Weighted %		
		Service level		85.02%

Table 5. Shows the purchasing activity plan and delivery schedule for the shipping company

Route 2																																			
Port A	Week	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
40 ft R (1 week lead time)	Ordered	300	300	300	300	300	300	300	300	300		117	300	300			300	300	300	300	300	300													
	Received		300	300	300	300	300	300	300	300	300		117	300	300			300	300	300	300	300	300												
Port B	Week	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
40 ft R (1 week lead time)	Ordered	300	300	300	300	300	300	300	300	300						34	300	300	300	300	300	300	300	300	300	300									
	Received		300	300	300	300	300	300	300	300	300						34	300	300	300	300	300	300	300	300	300	300								
Port C	Week	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
40 ft R (1 week lead time)	Ordered		200	400									372	400	400	400	400	400																	
	Received			200	400									372	400	400	400	400	400																

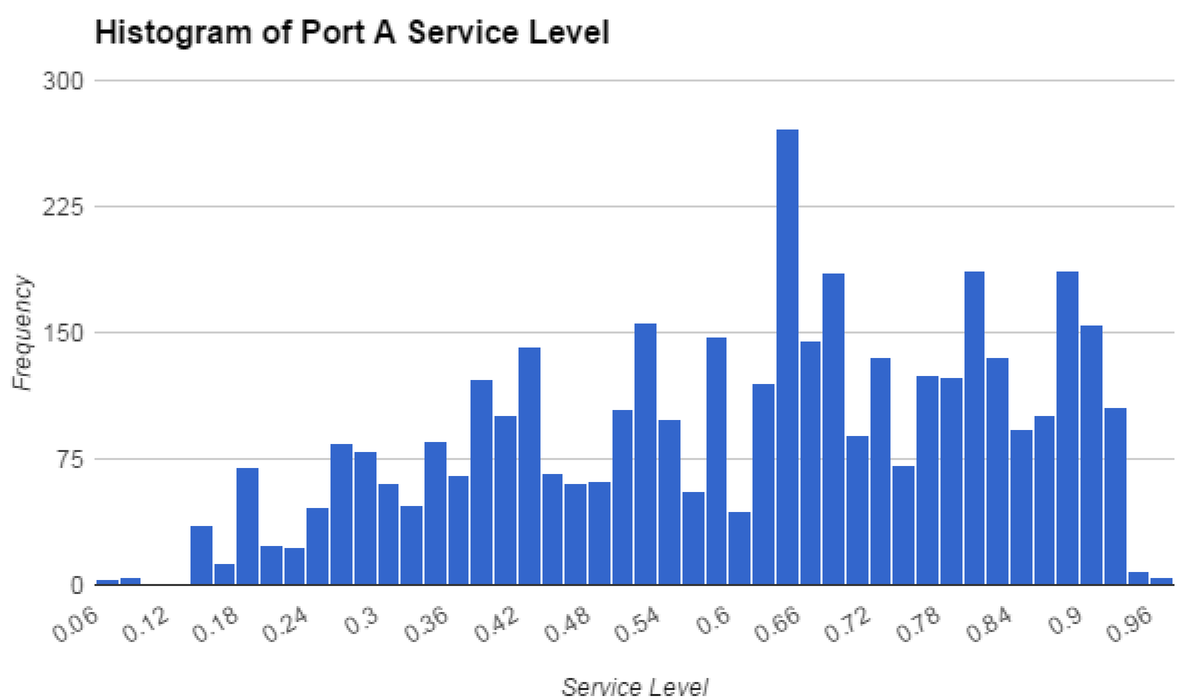


Figure 3: Port A Service Level Histogram

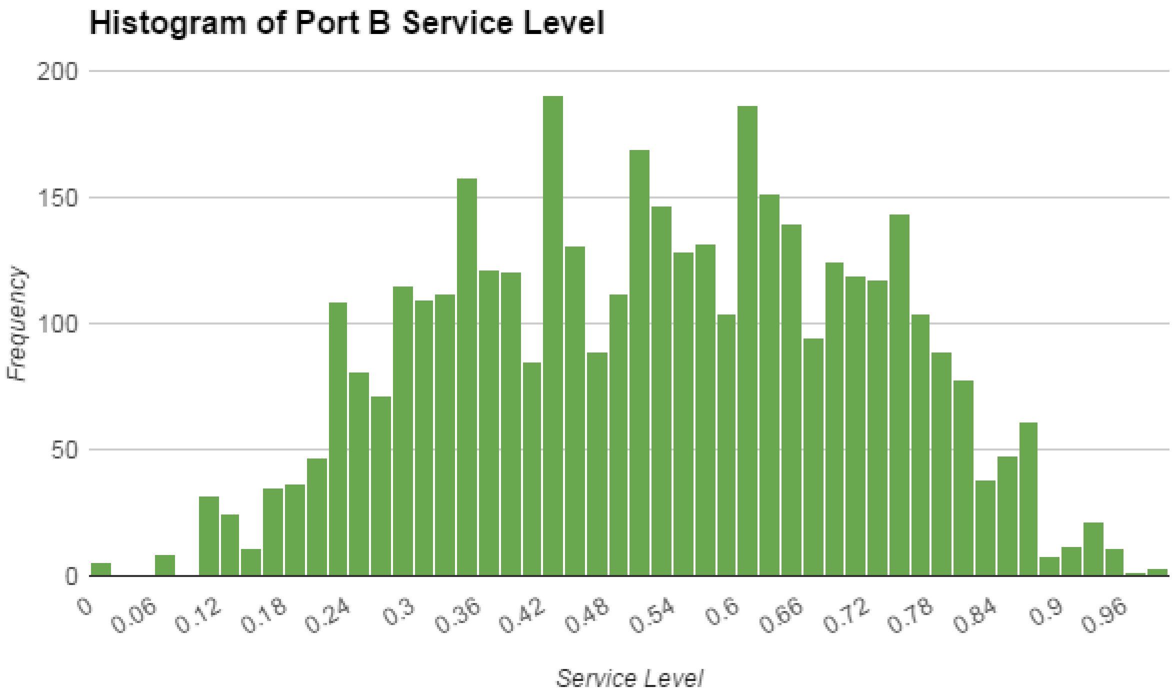
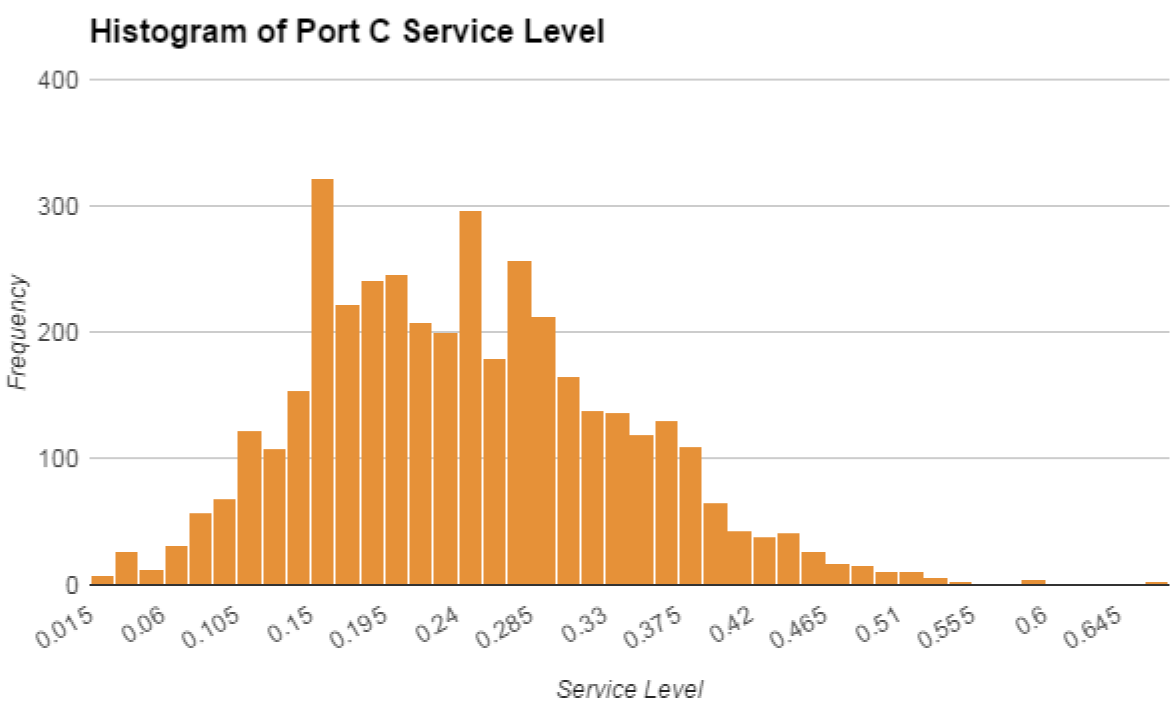


Figure 4: Port B Service Level Histogram

Figure 5: Port C Service Level Histogram



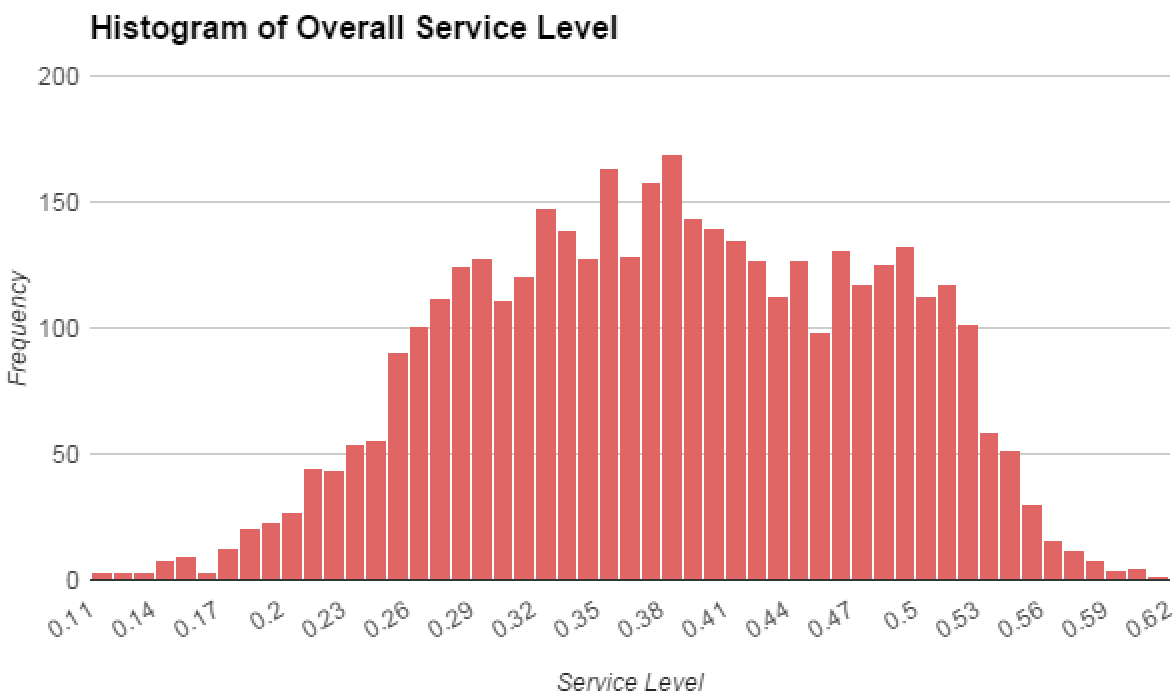


Figure 6: Overall Service Level Histogram

Table 6: *Compares Number of Shipments for each Path to the Maximum Number of Empty Containers for which Collapsible Containers still save the Shipping company money*

									Room Left				
Port 1	Port 2	Max # Containers	Price Collapsible	Price Reg	Price Difference	# of Trips Needed (Regular)	# of Trips Needed (collapsible)	Difference in cost/container	Boat 1 (250)	Boat 2 (600)	Boat 3 (375)	Capacity if filling Ships	Max Capacity
A	B	35	$163,125.00	$164,200.00	$1,075.00	2	1	1255	465	1165	715	18	34
A	B	71	$284,625.00	$285,520.00	$895.00	3	1	1255	679		1054	24	70
A	B	107	$406,125.00	$406,840.00	$715.00	4	1	1255	893			27	106
A	C	35	$162,600.00	$163,500.00	$900.00	2	1	1260	465	1165	715	18	34
A	C	71	$283,560.00	$284,100.00	$540.00	3	1	1260	679		1054	24	70
A	C	107	$404,520.00	$404,700.00	$180.00	4	1	1260	893			27	106
B	A	47	$218,625.00	$219,640.00	$1,015.00	2	1	1255	453	1153	703	24	46
B	A	95	$380,625.00	$381,400.00	$775.00	3	1	1255	655		1030	32	94
B	A	143	$542,625.00	$543,160.00	$535.00	4	1	1255	857			36	142
B	C	47	$218,625.00	$219,640.00	$1,015.00	2	1	1255	453	1153	703	24	46
B	C	95	$380,625.00	$381,400.00	$775.00	3	1	1255	655		1030	32	94
B	C	143	$542,625.00	$543,160.00	$535.00	4	1	1255	857			36	142
C	A	59	$273,240.00	$273,900.00	$660.00	2	1	1260	441	1141	691	30	58
C	A	119	$474,840.00	$474,900.00	$60.00	3	1	1260	631		1006	40	118
C	A	178	$673,080.00	$673,800.00	$720.00	4	1	1260	822			45	177
C	B	59	$274,125.00	$275,080.00	$955.00	2	1	1255	441	1141	691	30	58
C	B	119	$476,625.00	$477,280.00	$655.00	3	1	1255	631		1006	40	118
C	B	179	$679,125.00	$679,480.00	$355.00	4	1	1255	821			45	178