Transshipment Capstone Project

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Georgia Tech Panama Logistics Innovation & Research Center

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ISYE 6341 & 6342: Supply Chain Capstone Project

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EXECUTIVE SUMMARY

The purpose of this project was to create a simulation model that replicated as much as possible the operations involved in the movement of containers between the ports and the railway in the country. By creating this replication, the intention was to study and identify the bottlenecks and problems in the different stages. As well as to experiment on the potential effects of changes in the operations such as number of resources, schedules, etc.

For an easier understanding and management of the simulation, the model was divided into two major blocks: the port block and the rail block. These two blocks were then combined into one to observe the behavior of the complete system. The port block recreates the operations in the three major Panamanian ports: Balboa, Cristobal and Manzanillo; while the rail block recreates the operations of the Panama Canal Rail Company that travels across Panama from the Pacific Ocean to the Atlantic Ocean side and back.

After analyzing different basic scenarios for both the port and rail operations certain factors that characterize these operations have been found. Having loading resources working in the three tracks in Balboa simultaneously causes an increase of around 24% in the throughput of trains per day compared to having the resources work dedicated to one track at a time. Having 20 additional trucks transporting containers from the port yard to the rail stack provides an increase of 7% in the throughput of the northbound train operations. It was determined that 60 trucks in Balboa is the limit where adding more trucks does not provide any more benefits. Adding an RTG provided an 8% increase in throughput whereas removing an RTG did not cause a conspicuous negative impact on the system. On the other hand, adding a top loader accounted for a 6% increase in the throughput meanwhile removing one decreased the throughput by 4%.

In order to have a more conclusive result about what may be the limiting resources and difficulties on this complex system, further analysis and more data gathering is recommended. Note that the train operations were only simulated northbound, hence the loading of containers in the Atlantic side and unloading of these containers were estimated.

Overall this document presents a fairly complete and complex simulation that suggests further study of specific resource utilization and operational strategies that would very likely yield a more efficient system while at the same time providing a robust building block for simulating transshipment systems in Panama or similar operations elsewhere.

INTRODUCTION

The Panama Canal is a very well-known sea route to transport goods across the Pacific and Atlantic Oceans with great time and economy benefits, but this is not the only perk offered by choosing Panama as part of the route. Panama is in the process of expanding and refining the range of logistics services offered. One of these services is the intermodal interoceanic movement of containers: a system made of ports in the two oceans interconnected by rail, with the potential to get containers through the isthmus in under four hours[1]. In 2012, this system moved around 6.8 million TEUs of containers and it is expected to continue growing in the upcoming years. Currently, the number of TEUs the country handles is 75% of its total TEU handling capacity[2]. Figure 1 below depicts the yearly growth of the number of containers moved in the past 20 years.

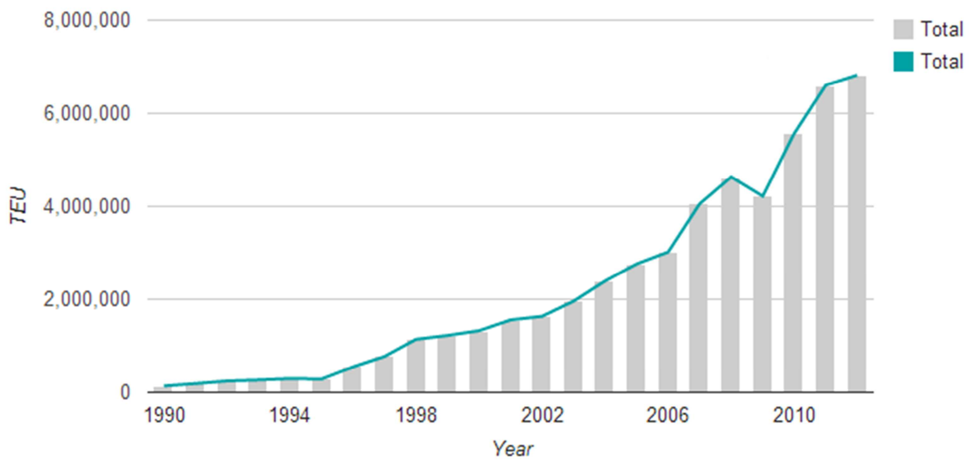


Figure 1 - Total Yearly Movement of Containers (TEUs)

Because of the expected growth in the number of TEUs handle, it is of great importance to understand the current operations of the intermodal transshipment movement of containers. It is of common knowledge that the administration of a system composed of different companies working together to achieve the seamless movement of goods is a complex matter which presents opportunities for improvement. This intermodal system is part of a bigger system encompassing all the possible destinations and routes that shippers and ocean liners may choose. The thorough understanding of the intermodal transshipment operation may help identify improvement strategies that could make the whole system more competitive. A well implemented and reliable transshipment process can potentially become part of the backbone of the logistic prowess of a country. This

[1] www.panarail.com
[2] http://logistics.gatech.pa/es/assets/seaports/statistics

project recognizes this potential and the necessity of a study to define, characterize and model the intermodal transshipment container movement in Panama.

PROBLEM DESCRIPTION

When vessels arrive to the Panamanian seaports and are unloaded, containers may have three kinds of movements. Depending on their final destinations, containers may stay at the ports and be loaded on a vessel that will take them to another port; they may be taken by rail to a port on the opposite side of Panama as an interoceanic movement; or less often they may stay in Panama as imports. This project focuses on the intermodal transportation of containers between the Port of Balboa in the Pacific Ocean side and the Ports of Manzanillo and Cristobal in the Atlantic Ocean side. It is considered an intermodal system because containers arrive by ship to the port, moved by train to the destination port and then loaded on another vessel using drayage movements where necessary.

Due to the complexity of the operations involved in the intermodal service it is required to have an understanding of the key players and their resources. The players include the port and rail administrators; and their resources include the different types of cranes, the truck fleets for drayage movements, locomotives and labor. In order to build the initial simulation, assumptions regarding the data received and the operations described as well as the scope of the system were made. These assumptions will be explicitly stated in the report.

To be able to analyze the process as a whole, a simulation was built using Simio, a software that permits the modelers to use their own intelligent objects in order to make the model resemble reality as close as possible. The simulation comprises the operations that permit this transport of containers. This simulation is intended to help understanding the utilization of resources in the process and allows to further examine the system by analyzing different scenarios. Figure 2 below shows a diagram of the current system.

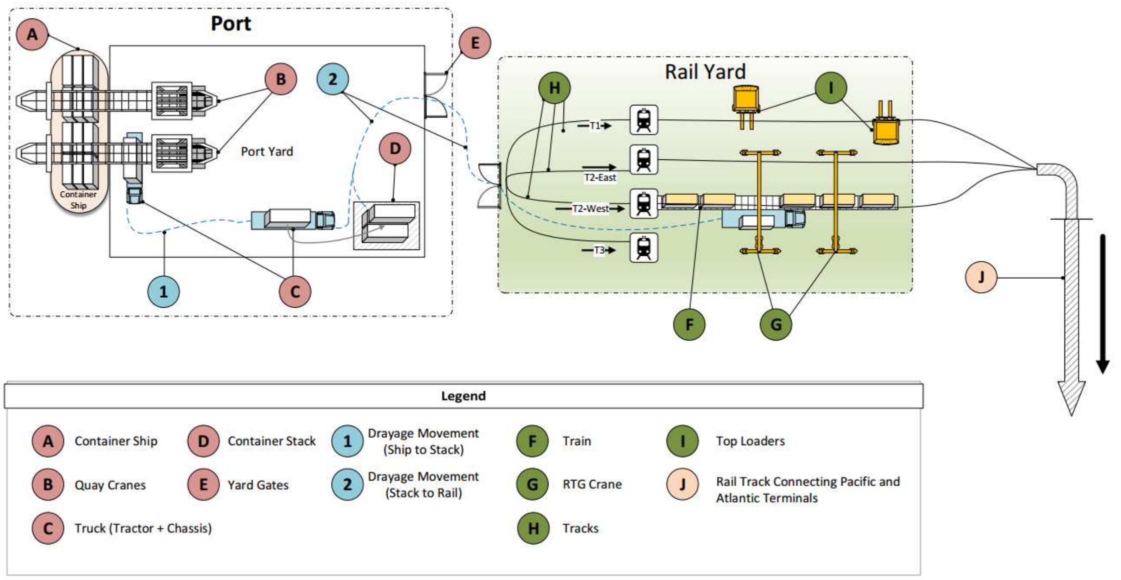


Figure 2 – System Representation

LITERATURE REVIEW

On their report (Bong Joo & Kap Hwan, 2011) mentioned that it is expected that rail transportation will become a more important mode of transportation in the near future. This is because environmental problems have become one of the most important concerns and rail transportation is considered to be environmentally friendly and a safe transportation mode.

In their paper, (Kulick & Sawyer, 1999) pointed out the benefits that come from using the modular approach on this type of system. These benefits include reusability for multiple projects, easy replacement of components, cost-effectiveness, ability to select application environment, distribution of development effort and scalability.

Dr. Kozan (Kozan, 1997) mentions in his article that the efficient and timely communication of information between the railways and its customers is highly important for the operations effectiveness. According to Kozan, there are three main needs to these users in terms of operation efficiency and should be taken into consideration: reliable delivery times, container pick-up and delivery cycles (delay free), and the ability to monitor real time information regarding container locations and their estimated arrival times. Moreover, he advises to analyze improvements in cargo-handling, and determine the optimal number of cranes needed per berth through changes in service rates.

METHODOLOGY

UNDERSTANDING THE CURRENT DATA

Researchers of the Georgia Tech Panama Logistics Innovation and Research Center have been studying and gathering data from the different players that operate the train. Some of this data includes:

- General procedures for:
    - Loading and unloading trains
    - Passenger service
- Train characteristics:
    - Amount of trains
    - Amount of locomotives
    - GPS availability
    - Container accommodation in the trains
    - Track availability for loading and unloading
- Loading and unloading times
- Travel times
- Departure schedules
- Vessels characteristics:
    - Type of ship (Panamax, PPX, SPX)
    - Size of ship
    - Size of containers
    - Number of containers
- Characteristics of resources that unload, move and load containers:
    - Cranes' operating times
    - Amount of trucks for drayage movements

BUILDING THE SIMULATION

For an easier management, the model was divided into two blocks: the port block and the railway block.

PORT BLOCK

The first one simulates the operations of the ports in general. These operations include components such as how ships arrive to the port, the movement of the containers from the time they are unloaded to the trucks to the time they are dropped at the rail yard and then loaded to the train.

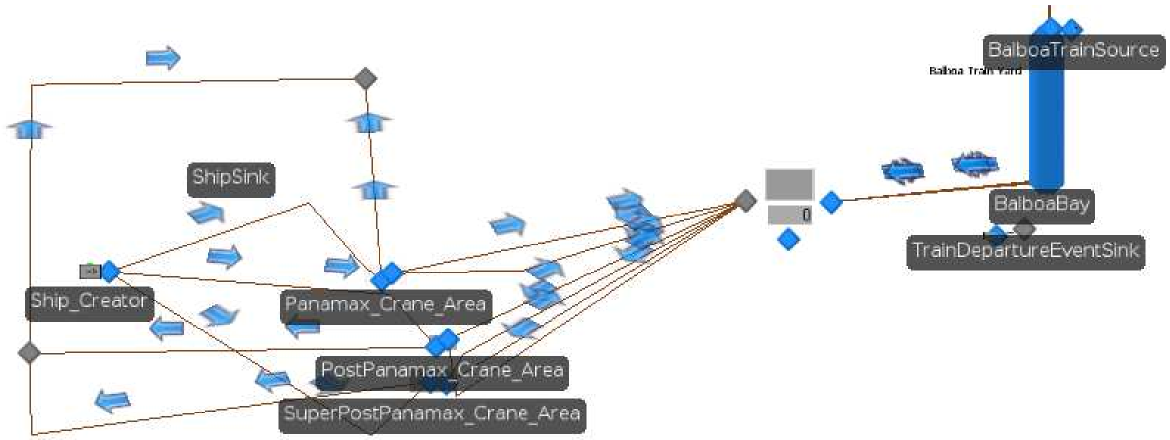


Figure 3 - Simio Screenshot of the Port Block (Northbound)

These components are represented in the simulation model by the following objects:

- Source
  - Vessels arriving to the Port of Balboa at the time and with the load declared on a port calls table.
  - This port calls table has representative column names allowing for intuitive modification of the input to the model. Important information that the model will extract from this table includes, but is not limited to:
    - Size (TEU Capacity and Vessel's Width) and Load (percentage of utilization of max capacity)
    - Type as determined by the size (Panamax, PPX, SPPX)
    - Mix of 20' / 40' containers (%)
- Servers
  - Berthing locations with their length and available cranes
  - Quay cranes that unload the containers from vessels to trucks, different crane types will be declared according to the ship size they can unload
- Paths
  - Predefined paths that the vessels, trucks and other mobile resources will traverse
  - The paths will have a total travel time from one point to another including time at customs and loading of the train if necessary. This is a decision made to simplify the model. The total time distribution will take into account:
    - Truck travel time
    - Quay cranes service times
  - Container movements represented include: crane to stack and stack to train.
- Resources
  - Vessels arriving at the port

    - Trucks for drayage movements
    - Containers (20 feet and 40 feet)
- Sink
    - Destination for the vessels once they are unloaded at the port.
    - Destination for the containers that are going to be loaded to the trains from the rail yard. This is necessary to force the entities (containers) to travel through the system.

RAIL BLOCK

This second block simulates the operations of the railway from the moment containers coming from the rail yard at the port are loaded in the train, when the train is dispatched, to the arrival of the train at the other ports and the unloading of the containers in those ports.

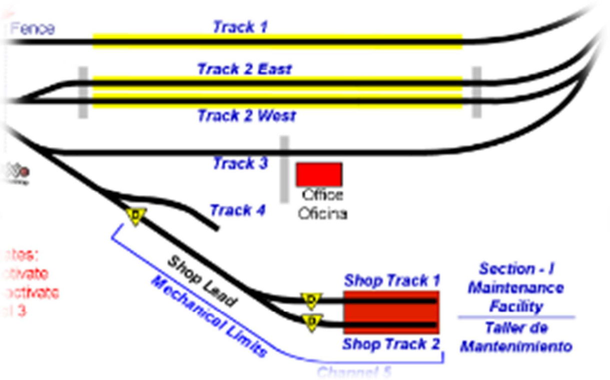


Figure 4 – Rail Tracks Available at Port of Balboa

This operation is represented in the model by the following objects:

- Source
  - Number of 20 ft and 40 ft containers loaded into the train. This number comes from the previous port block.
  - Number of trains loaded at Port of Balboa
- Resources
  - Seven trains, each composed by:
    - Locomotives that are the mechanical part of the train
    - Ten rail cars, each with five wells
    - Wells that can carry two 20 ft. containers and one 40 ft. container, or two 40 ft. containers as long as the combined weight does not surpass 55 tons
  - Trucks for drayage movement
  - Containers (20 feet and 40 feet)
- Servers
  - Train locations with their length and available cranes
  - RTGs and top loaders that unload the containers from trucks to trains, different crane types will be declared according to the train lane they are serving
- Paths
  - Predefined paths that the train, trucks and other mobile resources will traverse

- The paths will have a total travel time that will include the loading into the train if necessary by the movement operation. This is a decision made to simplify the model. The total time distribution will take into account:
    - Truck travel time
    - Rubber tyred gantry cranes (RTG) and top loaders' service times
- Sink
    - Train departure event sink to make sure the system recognizes that the train is no longer at Port of Balboa.
    - Destination for the trucks and containers once these arrive at the Atlantic side and are loaded to the trucks. This is necessary to force the entities (containers and trucks) to travel through the system.

Figure 5 - Containers Loaded into Wells

ASSUMPTIONS

After reviewing the data provided by the center, the following assumptions have been made:

1. In order to add some variability to the data, triangular distribution which uses the (MIN, Most Likely, MAX) values as parameters have been used due to the absence of hard data.
2. Vessels will arrive at a random time using a normal distribution with mean of 3 hours and standard deviation of 2 hours on the day declared in the ports calls table.
3. The type of vessel is determined by the following criteria: less than 2,500 containers is Panamax, from 2,500 to 5,000 containers is Post Panamax and above 5,000 containers is Super Post Panamax.
4. Every vessel uses two quay cranes to be unloaded.
5. The train is dispatched when it is full.
6. All the service times provided are accurate.
7. All resources including tracks, cranes, trucks, labor and trains will be available if not in use by another process. This means that resources never break down and no repairs are needed.

8. All of the containers that are placed in the rail yard come from the rail stack of the port.

SIMULATION PROCESSES

The simulation aims to resemble the real world operations, in order to understand at which depth and detail each operation was simulated it is not only necessary to know the previously stated assumptions but also to describe the modeled processes and how we implemented the assumptions, data and operational logic into the actual model.

PORT PROCESSES

Ship arrival, berthing, unloading and transport:

Arrival: The port has a schedule of vessels arriving each day, this is usually called the "port calls". The ships are then created according to this table and bring a load of 20 and 40 feet containers as specified in the mentioned table. The ship is loaded at a 100% capacity and the mix of containers is a random value in the range of 60% to 80% 40 ft. containers and the remainder are 20 ft. containers.

Berthing: Depending on the vessel's TEU capacity and width they are classified as either Panamax, PostPanamax or SuperPostPanamax. Using this classification, the vessel is then assigned to a berthing position. The Panamax vessels can use any position available, the PostPanamax can use positions for Panamax and PostPanamax, and the SuperPostPanamax can only use the position exclusive for that type. The berthing position has a certain amount of quay cranes assigned and they unload one 40 ft. container or two 20 ft. containers at a time and loads the truck if this is available, if not it waits for a truck to reach its position.

Berth to Rail Stack Truck Movements: After the ship is berthed the quay cranes start the unloading process and the trucks start picking up the containers and taking them to the rail stack. After dropping the container into the stack the truck will make the return route to the Truck Parking Site or to the Berth that needs pick up of containers that the quay cranes are unloading. The model uses 'timepaths' to simulate the travel time between the berthing positions and the stack.

Containers destinations: According to the studies of the real operations not all the containers unloaded from the ship are going to the rail stack, some of them are going to other ships inside port of Balboa or as import to Panama. To simulate this all the containers are unload but only 60% of them go to the stack, the rest are taken outside the model and effectively cease to exist inside it. In real life operations, the cranes and trucks used for unloading the containers with destination to the rail yard are the same unloading resources for the containers with other destinations (e.g. containers that stay in Panama as imports)

The port block as an independent entity finishes in the rail stack. At this point, the truck pool for the path between the rail stack and the port is a component of the whole system that includes the rail yard. This is explained in more detail in the next section.

RAIL YARD OPERATIONS

Train loading, departure logic, interoceanic travel, parking, queuing, unloading and how the system loops.

Rail stack to train track and rail car movement:

Stack pickup and railcar assignment: The effective throughput of the port unloading operations is the input for the rail stack. This rail stack is then, after the “steady state” is reached, loaded with a mix of containers of 20 ft. and 40 ft., all of them in the queue to be loaded into the trains. In a FIFO fashion each container will request a truck pickup, which will take a certain amount of time (reshuffling + load time). After the truck is loaded it will be assigned to a railcar destination, in the following order:

- The first railcar of the first track will be loaded, then the first railcar of the second track and then the first railcar of the third track. The next container will check which type of container is loaded already in the railcar and will go load the first railcar that has capacity left. If all the first railcars are full, it starts with the second row of railcars, meaning railcar two of first track, railcar two of second track and rail car two of the third track. This happens iteratively effectively filling the train up which the proper capacity constraints.
- The previous process is to replicate the ‘north to south’ loading order.
- This loading logic of various tracks at a time will hereon be called ‘parallel loading’ logic. It differentiates with the ‘dedicated loading’ logic which seeks to load one track at a time assigning all the possible resources to each track before continuing with loading of the next track.
- Each railcar can only be loaded with either :
    - Two 20 ft. containers and one 40 ft. container on top
    - Two 40ft Containers

RTGs and Top loaders: Currently the truck reaches its assigned railcar then it enters the queue for unloading. This request can be taken care of by either an RTG or a top loader, depending on the track. Tracks 2W and 2E have RTGs available, and Track 1 and 2E top loaders available. This means that Track 2W is served exclusively by RTGs, but shared with Track 2E, and Track 1 is served exclusively by top loaders but shared with Track 2E.

This makes Track 2E the one that will logically load faster since it has available both RTGs and top loaders.

Train Departure: The train monitors how many TEUs is holding at all times. When the monitor reaches 200 TEUs the train is full and will depart. At this instant, a traffic control process triggers and makes the train leave immediately if the yard is not busy; the train waits until an incoming train finishes parking; or the train waits until an outgoing train finishes leaving. This simulates train coordination interactions in arrivals and departures. The simulation limits itself to trains going to MIT only. According to our sources most of the trains are loaded with containers going to only one port, and not mixed.

Interoceanic rail track and sidetracks: The interoceanic route is one way in the real world, but there are two side tracks that allow for traffic to go on the opposite direction as long as it is able to wait in the sidetrack to allow the incoming train to pass. What the model does is very similar, it allows traffic both ways but makes the train wait in the sidetrack until it finishes passing by if an opposite heading train is already in the track. This will add waiting times into the system and these is tracked too. The trains will wait in the sidetrack if waiting for a track to become available in the destination rail yard.

The northbound travel takes on average 1.5 hours.

Train Arrival at MIT:

After making the northbound trip, and if a track is available, the train will be parked in the MIT rail yard and unloaded by the RTGs or top loaders. All the railcars will enter the unload queue, one train at a time in a “south to north” order.

At this point the train will take 2*(Load Time (distribution)*Rail Car Numbers (50)) to unload, effectively replicating both the unloading of the incoming containers and the loading of the train. The assumption that each truck comes with a container heading southbound is made. It is important to remark, though, that the actual loading does not take place in the southbound operations but the time added should replicate the amount of time resources are utilized and the train held in place for unloading/loading operations. The unloading is simulated and the containers will head into a sink that represent the entrance of this container into the MIT port block where the container will board another ship. This sink object monitors the effective throughput of the whole system by keeping statistics on the containers that processes.

SouthBound:

When the train is totally unloaded (and the loading time has passed) the train will depart, not without first running the traffic control process to ensure it does not get in the way of an incoming train.

Once it makes the interoceanic travel, the train will hold in the sidetrack near the Balboa rail yard, and when there is a track available it will park. Now the unload time will pass before the train is ready to be loaded again.

At this moment the trucks are notified that there is a new train available for loading and will start bringing more containers headed to MIT until the departure logic kicks in and the whole process will repeat itself over and over for the seven trains until the length of the simulation run is completed.

All these parameters and times are specified in our baseline parameters section as well as in the assumptions.

RESULTS, DESIGN OF EXPERIMENTS AND ANALYSIS

To be able to analyze the system and locate the bottleneck some scenarios have to be examined in order to correctly determine the factors and resources that cause the system to not perform at its optimal level. To better understand the whole system, different scenarios (experiments) have been made to determine if the problem can be easily detected this way.

BASELINE SCENARIO

In order to analyze the results a baseline scenario was created. The details for the baseline are listed in the table below.

Location	Parameter	Value	Units
System	Amount of trains	7	trains
Balboa	Amount of tracks	3	tracks
	Amount of trucks	40	trucks
	Amount of RTGs	4	RTG cranes
	RTG load speed	1	minute per movement*
	RTG unload speed	1.4	minutes per movement*
	RTG tracks	2W, 2E	tracks
	Amount of top loaders	4	top loaders
	Top loader load speed	1	minute per container
	Top loader unload speed	0.7	minutes per container
	Top loader tracks	2E and 1	tracks
MIT	Amount of tracks	3	tracks
	Amount of trucks	40	trucks
	Amount of RTGs	3	RTG cranes
	RTG load speed**	2	minutes per movement
	RTG unload speed**	2.8	minutes per movement
	RTG tracks	1W and 1E	tracks

	Amount of top loaders	4	top loaders
	Top loader load speed	2	minutes per container
	Top loader unload speed	1.4	minutes per container
	Top loader tracks	1W and 2	tracks
*** A movement can refer to a movement of one 40ft container, two 20ft containers, or one 20ft container. RTGs can perform movements of two 20ft containers whereas top loaders can only move one container at a time, regardless of the size.**			

Table 1 - Baseline Parameters

COMPARISON BETWEEN SCENARIOS

TRAIN OPERATIONS

For measuring more accurately the impact of the different components of the train yard block, the model generates as many containers as needed directly in the rail stack. It can be assumed there is always availability of containers in the stack and a constant demand for truck pickup to drop at the train.

By looking into the single loading scenario, dedicating resources to each track, the options presented to either look into the bottleneck there or implement a more real and complex loading logic. This last one is known as "parallel loading", which basically means all resources available, intelligently, throughout all the tracks are used.

The new model was created and now a single loading scenario was available to be compared with the new baseline, the parallel loading scenario, with the same amount of resources in both. These resources as stated in the previous section defined 40 trucks for the stack-train operation, 4 RTGs and 4 top loaders.

In this section the model is decomposed into smaller pieces to study the impact of changing their values into extremes and therefore identifying better resource pool sizes for this operation.

The subsequent table indicates what scenarios were analyzed and what parameters were changed. Note that the baseline scenario adopts the parallel loading logic. These scenarios were only used to analyze the northbound rail operations.

No.	Scenario Description	Parameters Changed
B	Baseline - Parallel Loading	None
1	Single Loading	Loading is done in one track at a time
2	Adding an RTG to Balboa	5 RTGs in Balboa
3	Removing an RTG from Balboa	3 RTGs in Balboa
4	Adding a top loader to Balboa	5 top loaders in Balboa
5	Removing a top loader from Balboa	3 top loaders in Balboa

6	Ten trucks less	Amount of trucks in Balboa
7	30 trucks more	Amount of trucks in Balboa
8	110 trucks more	Amount of trucks in Balboa

Table 2 - Scenario Descriptions

TRUCKS AND THE NEW BASELINE

Initially the study allowed showed that, in a single loading scenario, the trucks queue up waiting for the RTGs or top loaders to unload them. So, there was not a significant increase in productivity (decrease in loading time or track utilization) by increasing the number of trucks of this scenario by more than 40 trucks.

Although this information was gathered from the first basic scenario, the need arises for more accurate insights to the real operations. The new baseline scenario was created and the following differences were observed:

The same amount of resources were used for the tracks.

	Single Loading (1)	Paralel Loading (B)
Throughput(containers)	774	**963**
Trains per day	6.3	**7.1**
Load Time (Avg. HRs)	1.54	1.83
Fastest Track (first in queue to park)	no benefit in prioritizing	Track 2 East
Bottleneck	Truck delivery	Trucks, RTGs and top loaders (in order)

Table 3 - Single Loading vs. Parallel Loading

A more in depth look into the previous table allows to make some statements regarding the system:

- Single loading is preferable if load time is the only benchmark, but parallel loading allows for more throughput of the system, which is in the end the primary means of reducing the overall time in system for the containers.
- The prioritization of Track 2 East allows this track to be the busiest throughout the whole run, meaning a train will always be parked and loading the fastest loading track, effectively increasing the throughput of the system.
- Prioritization of Tracks in the single loading scenario leads to staggered and lagged trains, since it presents the option to either continue working on the new train in the priority track(making the other 2 wait even more to be served) or continue serving the rest of the trains (negating the benefits of priority parking)
- In scenario 1, when single loading was the loading logic, our bottleneck was mainly the trucks delivering containers to the train. This bottleneck shifts to the RTGs and top loaders. While trucks are waiting for service from the RTGs after reaching the

“steady state” in the loading process (after the first 40 trucks have looped once), it can be observed that there is a waiting time of the RTGs and top loaders to receive the second “wave” of trucks.

TRUCKS

Several scenarios were ran in order to find the point at which the increase in trucks ceased to give valuable returns in throughput.

	B	30 Trucks	60 Trucks	150 Trucks
System	73	72	75	75
T2E	19	19	23	23
T2E	42	49	48	47
T1	10	4	4	5

Chart 1 Trains Loaded

As observed in the graph there is an increase of 1 in trains sent to the Atlantic side this is roughly 200 TEUs more or 20 TEUs per day, not very significant but depending on the economics of each TEU moved it could be further studied to add the 10 or 20 trucks, to get the benefit. Even more interesting is that by adding a whopping 90 trucks (over 2 times the available at the moment) there is no increase in trains sent to the Atlantic side.

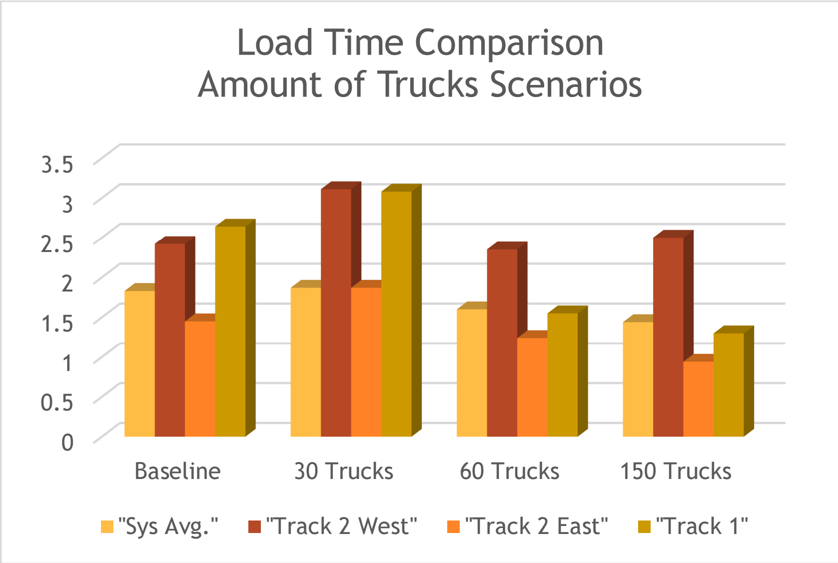


Chart 2 Track Load Time

In this graph it can be appreciated how the behavior of the load times is pretty intuitive, increasing proportionally with the decrease of trucks available and decreasing with the increment of available trucks, **a threshold for this linear increase could be observed in the 60-70 truck range**. Other interesting insights that this experiment provided is the fact that there was no visible increase in throughput even though the load time decreased, this is particularly interesting since it is just observable if the system takes into account the fact that load time can decrease up to a point in which the bottleneck will be the availability of the RTGs and top loaders.

RTGS AND TOP LOADERS

Even though they serve the same purpose, since they are available to different tracks, and track prioritization and availability happens, the RTGs and top loaders affect the system each in its own unique way and scale.

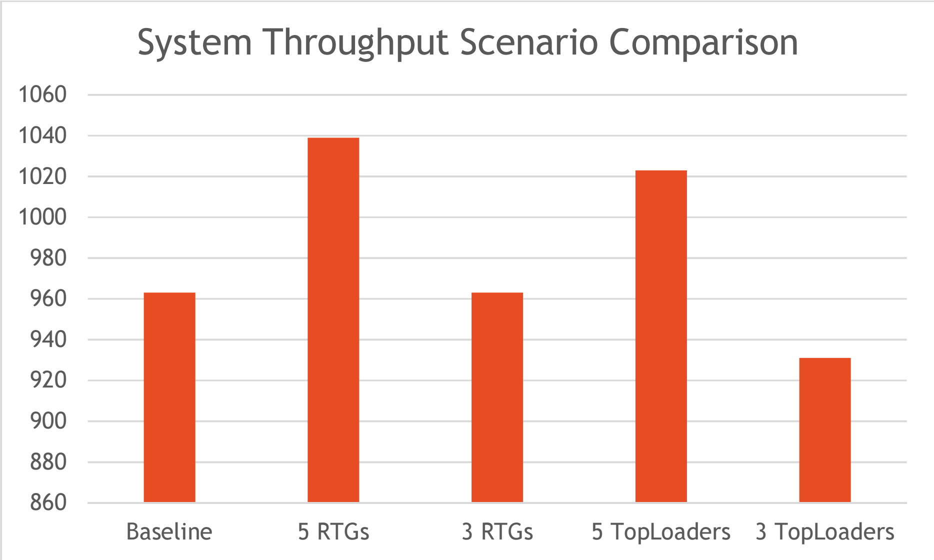


Chart 3 System Throughput Scenario Comparison

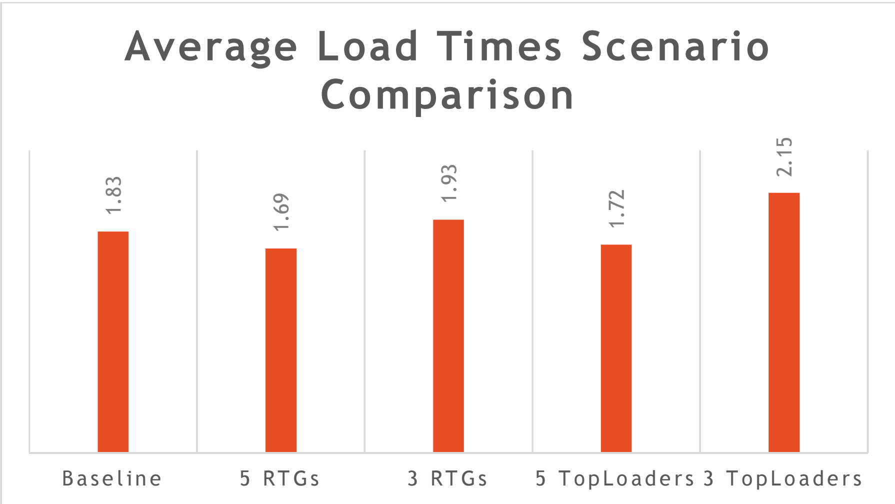


Chart 4 Average Load Times Scenario Comparison

Just the same way it happened with the trucks, the intuitive expected results were obtained by watching a proportional decrease in load time with the increase of RTGs or top loaders available in each track.

More noticeably and useful insights may come from the load time in each track, from which it can be extracted the reason why prioritizing the train parking and loading can be of benefit to the whole system. These can be observed in the following graph.

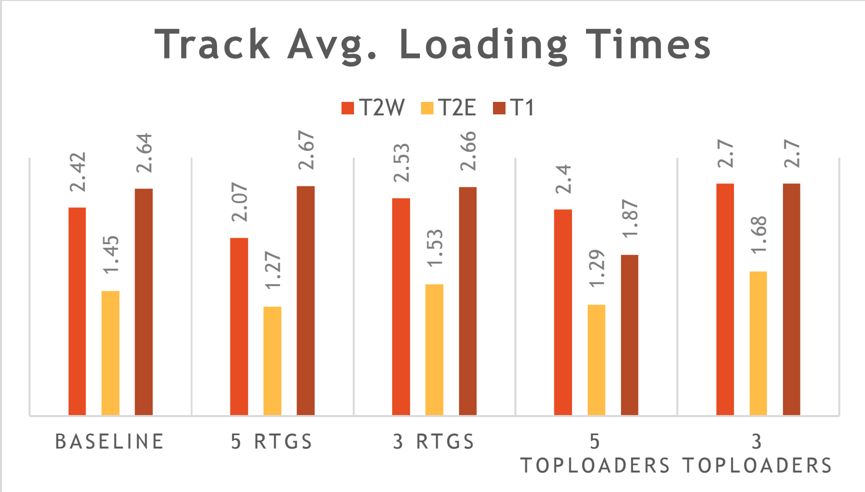


Chart 4 Average Load Time Scenario Comparison

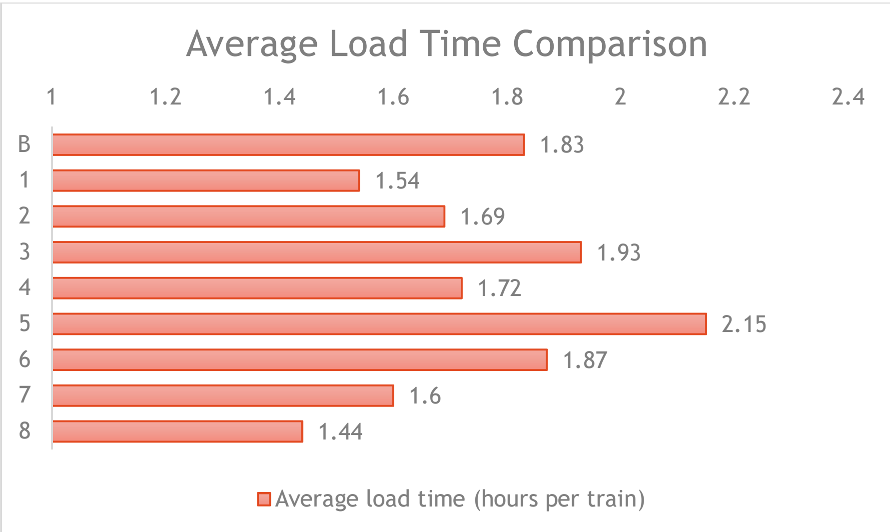


Chart 5 Scenario Load Time

No.	Scenario Description	Load time (hours)			
		System	T2W	T2E	T1
B	Baseline - Parallel Loading	1.83	2.42	1.45	2.64
1	Single Loading	1.54	2.1	1.21	1.26
2	Adding an RTG to Balboa	1.69	2.07	1.27	2.67
3	Removing an RTG from Balboa	1.93	2.53	1.53	2.66
4	Adding a top loader to Balboa	1.72	2.4	1.29	1.87
5	Removing a top loader from Balboa	2.15	2.7	1.68	2.7
6	Ten trucks less	1.87	3.11	1.87	3.08
7	30 trucks more	1.6	2.35	1.24	1.55
8	110 trucks more	1.44	2.5	0.94	1.3

Table 4 - Loaded Trains per Track

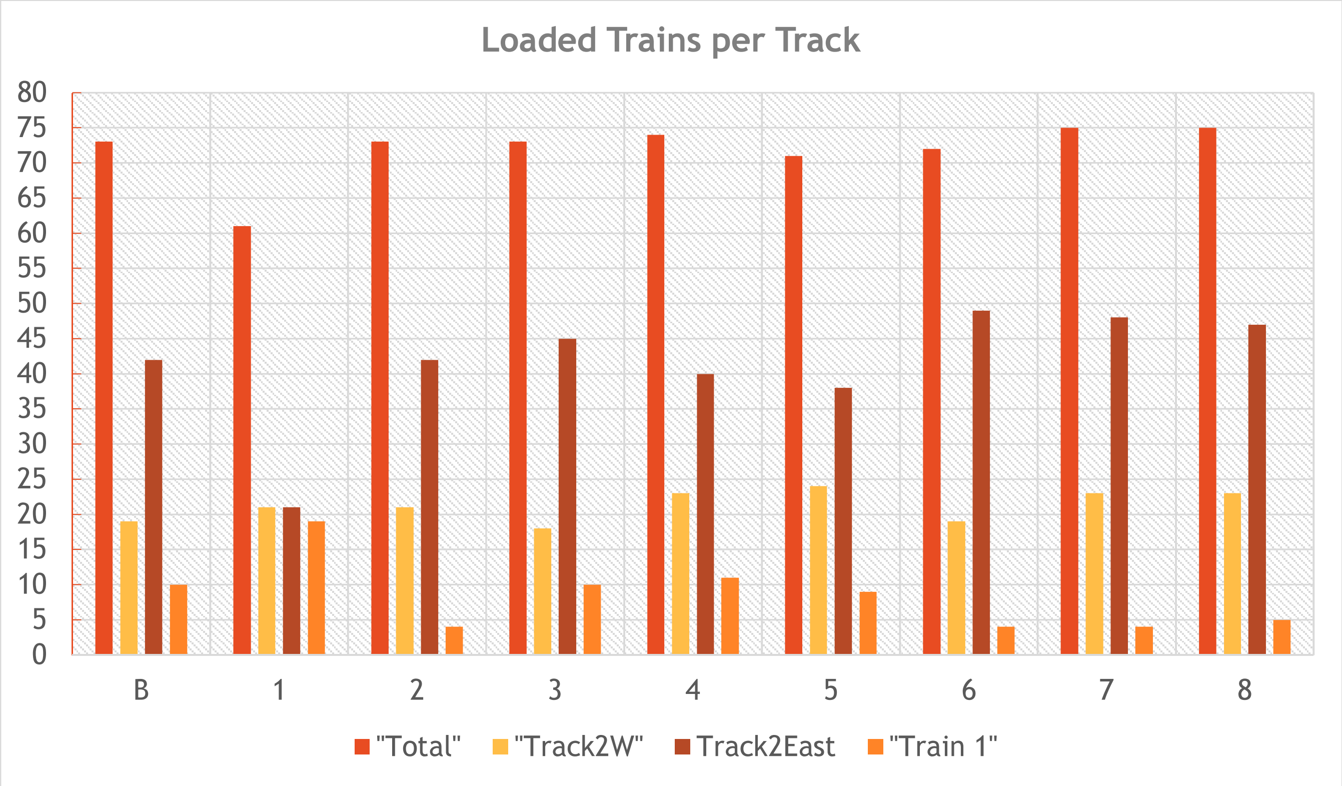


Chart 6 Loaded Trains per Track Scenario Comparison

GENERAL METRICS

A more general overview of the results can be appreciated by looking into all the information together. It can be concluded that the single loading, dedicated resources is not a good operation for maximizing throughput, while the proper handling of train parking prioritization and availability of RTGs and top loaders are the decisions that will impact the most our system. Increasing trucks on the other hand has certainly a low impact and diminishing with the number of trucks, compared with the reported availability of trucks at the moment just a 10% decrease in load time and a 7% increase in container throughput is achievable by increasing in 50% the trucks available. This strategy requires a cost-effectiveness analysis to be considered for implementation. The impact of RTG and top loaders is certainly greater but also more analysis of cost/benefit would have to be made.

No.	Scenario Description	Throughput (containers/day)
		System
B	Baseline - Parallel Loading	963
1	Single Loading	774
2	Adding an RTG to Balboa	1,039
3	Removing an RTG from Balboa	963
4	Adding a top loader to Balboa	1,023
5	Removing a top loader from Balboa	931
6	Ten trucks less	943
7	30 trucks more	1,030
8	110 trucks more	1,030

Table 5 - Scenario Throughputs

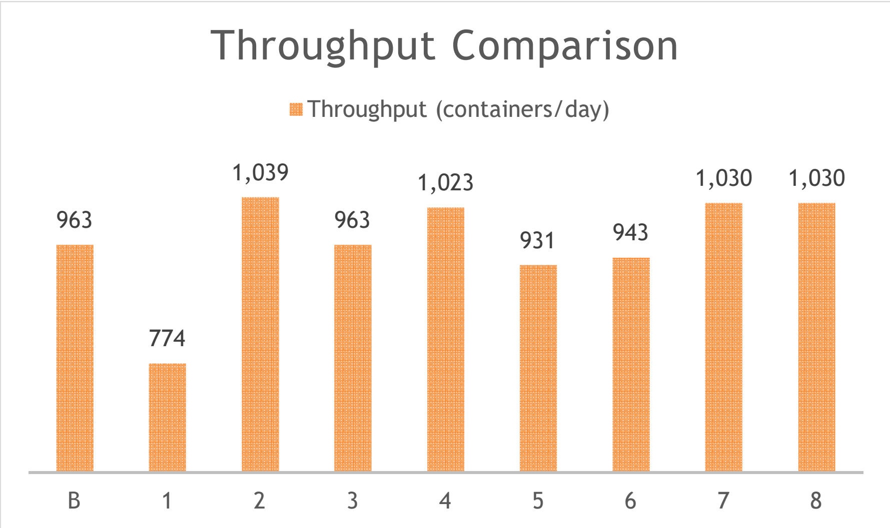
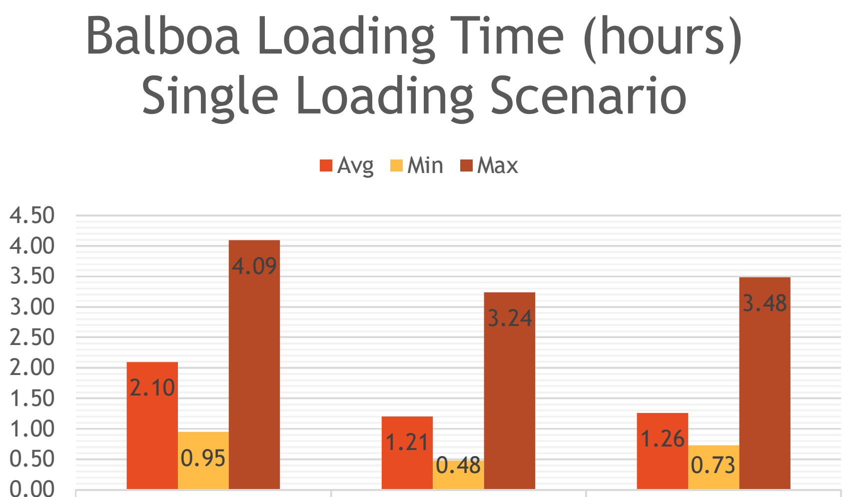


Chart 7 Throughput Comparison

Since the container throughput can vary in TEU (i.e. two containers can be either two, three, or four depending on the 20 ft. /40 ft. mix) and TEU is the way the economic benefits are calculated, a more in depth analysis would have to be made for transforming the container throughput into income. In the previous table it can be appreciated the impact of the different changes in the trains loaded and sent to the Atlantic side, each train is 200 TEUs, so this would be a much better way of measuring system effectiveness in an economical point of view. Along with track utilization, the relationship between the equipment investment and proper track output can be made in order to make future decisions on the infrastructure of the rail yard.

TRACK UTILIZATION

As mentioned before, Track 2 east shares resources with both of the other tracks. If the four RTGs (combined throughput of 100 movements per hour) and the four top loaders (combined throughput of 140 containers per hour) were used to load a train parked in Track 2 East, a loading time of thirty minutes could be achieved. The following chart depicts how fast a track can be loaded if all the resources are dedicated to a track. The minimum values give us these insights.



	Track 2 West	Track 2 East	Track 1
Avg	2.10	1.21	1.26
Min	0.95	0.48	0.73
Max	4.09	3.24	3.48

Chart 8 Balboa Loading Time using Single Loading

The percentages indicate how much each train on average preferred going to any of the three tracks. The logic behind the simulation model instructs the trains to go to track 2 east first because of the higher amount of loading resources. In the following table we can see that the preferred track, when using the parallel loading logic, is track 2 east. This makes us consider if in the real life operations, Balboa is prioritizing the use of track 2 east as the preferred track for loading and unloading.

Scenario		Metrics						
		Trains loaded				Track Utilization		
		System	T2W	T2E	T1	T2W	T2E	T1
B	**Baseline - Parallel Loading**	73	19	42	10	26%	58%	14%
1	**Single Loading**	61	21	21	19	34%	34%	31%
2	**Adding an RTG to Balboa**	73	21	42	4	29%	58%	5%

3	**Removing an RTG from Balboa**	73	18	45	10	25%	62%	14%
4	**Adding a top loader to Balboa**	74	23	40	11	31%	54%	15%
5	**Removing a top loader from Balboa**	71	24	38	9	34%	54%	13%
6	**Ten trucks less**	72	19	49	4	26%	68%	6%
7	**30 trucks more**	75	23	48	4	31%	64%	5%
8	**110 trucks more**	75	23	47	5	31%	63%	7%

Table 6 - Track Utilization

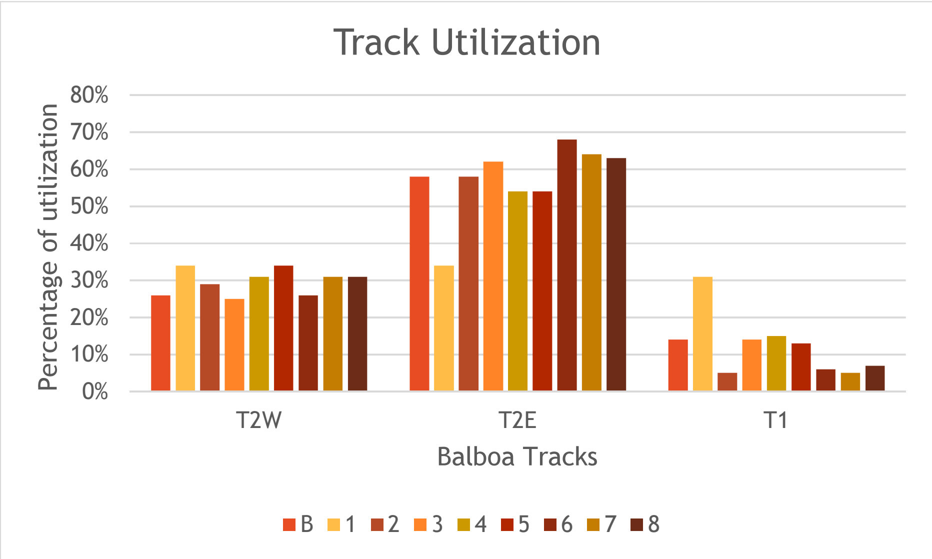
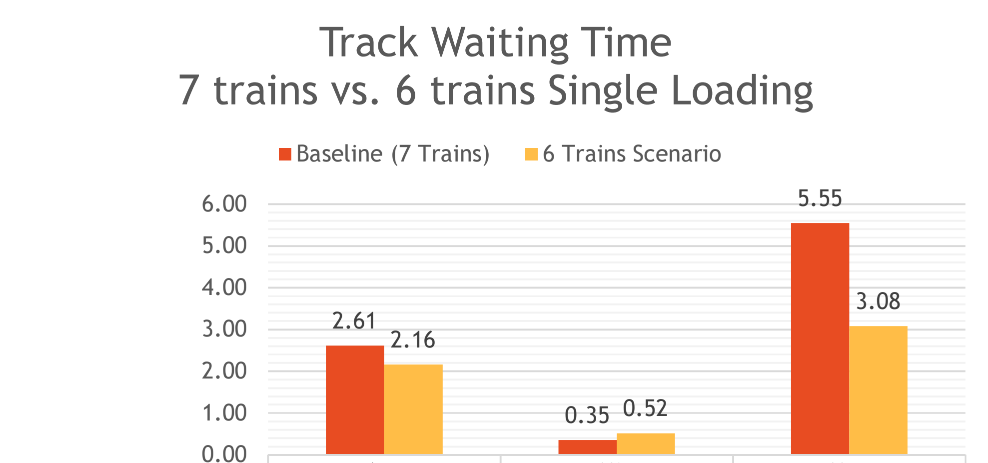


Chart 8 Track Utilization

When using single loading the track waiting time was considered mostly in the southbound sense. In other words, trains had to wait on the sidetrack for a track to be available in Balboa. A scenario that considers only six trains transporting containers (the baseline considers seven trains) was analyzed to see the impacts of reducing a train. Removing a train would reduce the average waiting for a track by approximately half an hour. There is still a waiting time, so removing a train from operations does not alleviate the bottleneck. From another perspective, it can be inferred that when using single loading, a train can go into maintenance anytime because it will not eliminate the bottleneck and therefore productivity would not necessarily decrease. The following chart depicts the numbers mentioned.



	Avg	Min	Max
Baseline (7 Trains)	2.61	0.35	5.55
6 Trains Scenario	2.16	0.52	3.08

Chart 9 Track Waiting Time in Single Loading

DWELL TIMES

It was initially thought that Balboa was the bottleneck in the simulation. The following numbers provide understanding that trains on average spend waiting around 3.5 hours for a track to be available in MIT so that unloading and loading can be done. Note that certain information pertaining to MIT was not readily available so loading times in MIT of 1.5 hours and unloading times in Balboa of 2 hours were assumed in the model. A more in depth analysis of these numbers may provide better insights on determining the bottlenecks in the whole intermodal system.

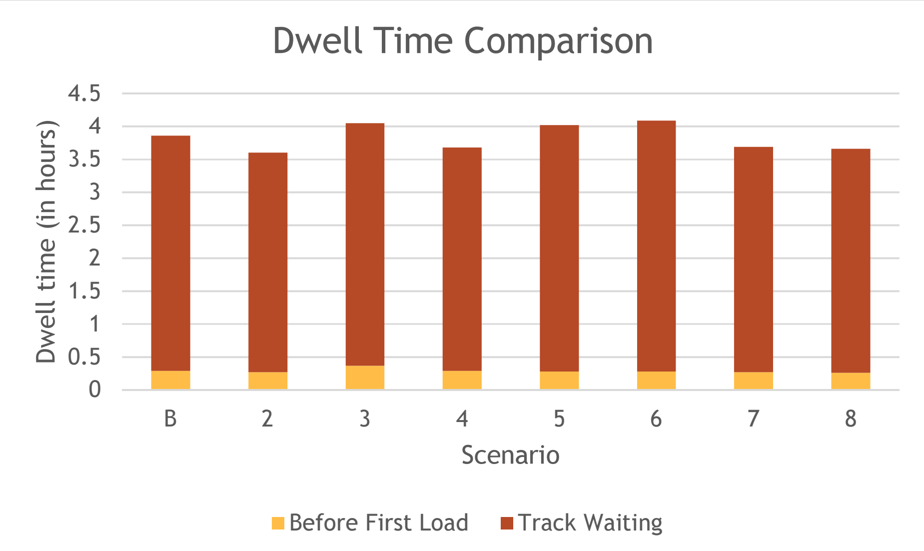


Chart 9 Dwell Time Comparison

No.	Scenario Description	Dwell on Track Before First Load	Track Waiting	Total Dwell Time
B	Baseline - Parallel Loading	0.29	3.57	3.86
2	Adding an RTG to Balboa	0.27	3.33	3.6
3	Removing an RTG from Balboa	0.37	3.68	4.05
4	Adding a top loader to Balboa	0.29	3.39	3.68
5	Removing a top loader from Balboa	0.28	3.74	4.02
6	Ten trucks less	0.28	3.81	4.09
7	30 trucks more	0.27	3.42	3.69
8	110 trucks more	0.26	3.4	3.66

Table 7 - Scenario Dwell Time

Single track loading presented a very unbeneficial characteristic: trains had to dwell for around 4.8 hours before the loading resources started loading the trains' first railcar. As it can be seen in the previous table, the dwell time was minimal when using parallel loading. This was one of the primary reasons why parallel loading logic was adopted as the baseline instead of single loading; it helps resemble the real operations of the train and bottlenecks are addressed more realistically.

The following chart indicates that trains spend on average 4.8 hours before they receive a first container. When the 6 train scenario was considered, using the single loading approach, this dwell time reduced by 0.9 hours.

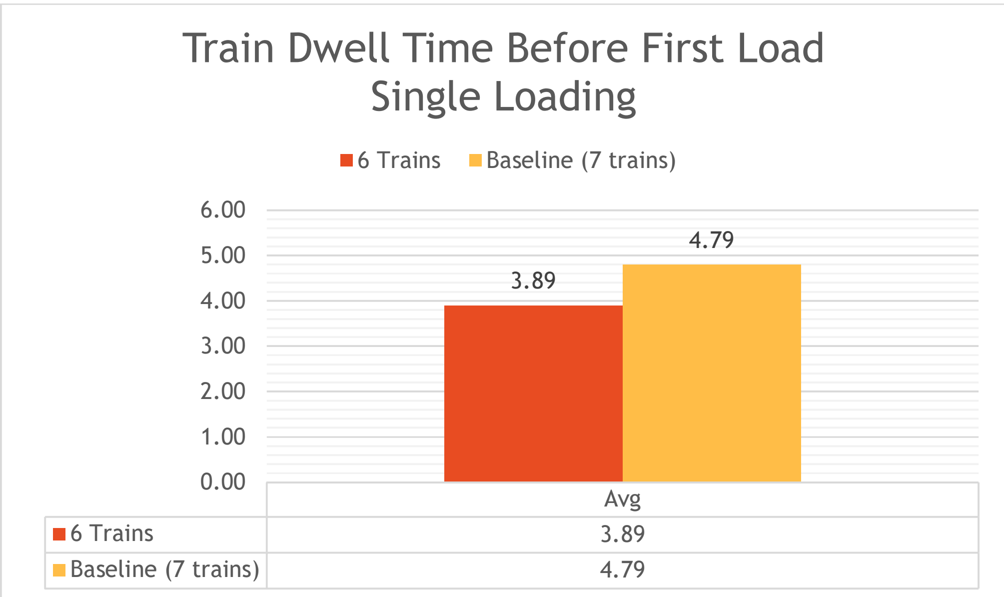


Chart 10 Train Dwell Time Before First Load Single Loading

PORT OPERATIONS

In order to analyze the results a baseline scenario was also created for the port operations. The details for the baseline are listed in the table below.

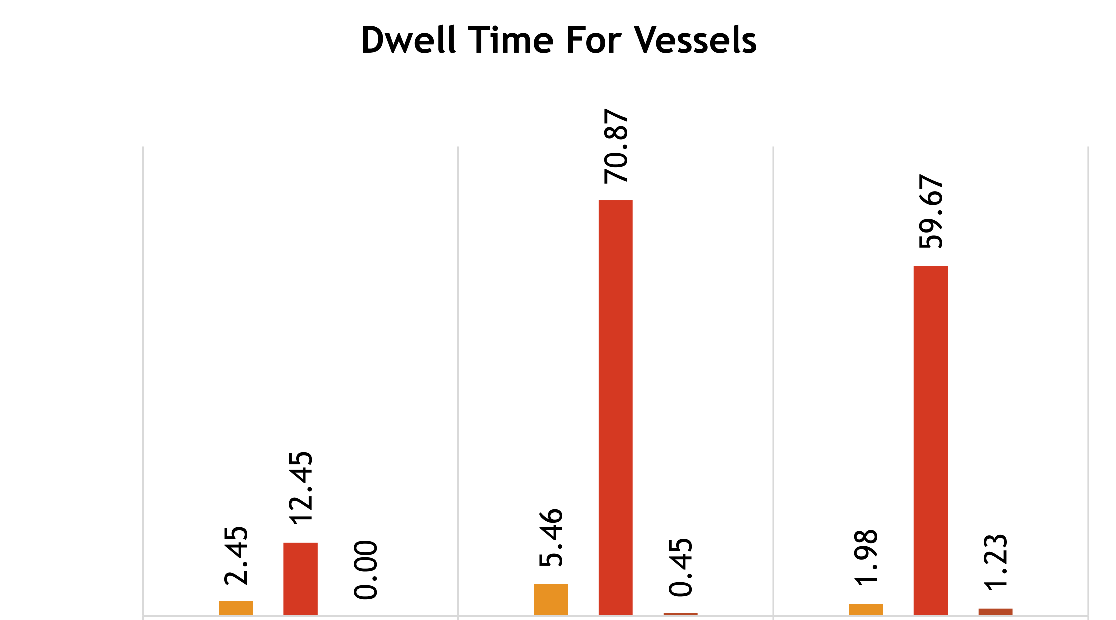
Location	Parameter	Value	Units
System	Amount of quay cranes	6	Cranes
	Quay cranes load speed*	30	Movements per hour
	Quay cranes unload speed*	30	Movements per hour
	Amount of trucks for pool 1	20	Trucks
	Amount of trucks for pool 2	20	Trucks
	Amount of trucks for pool 3	20	Trucks
	Travel time from vessel to train stack	20	Minutes
	Travel time from stack to train	15	Minutes
*** A movement can refer to a movement of one 40ft container, two 20ft containers, or one 20ft container. RTG's can perform movements of two 20ft containers whereas top loaders can only move one container at a time, regardless of the size.**			

Table 8 - Port Operations Parameters

From the port call tables it is determined the amount of containers that each vessel delivers. The arrival time of these vessels follows a normal distribution with mean of 3 hours and standard deviation of 2 hours. As mentioned before, the type of vessel is determined by the amount of containers it carries. Depending on the size of the vessel, then it is the amount of berthing positions it can use. For instance, a Panamax can use either of the three berthing positions; while a SuperPostPanamax can only use one. These containers are then unloaded and loaded by the quay cranes into the trucks to go to the rail yard. Each berthing position is served by a different pool of trucks. Before arriving to the rail yard, a percentage of these containers leave the system to model the fact that in the real world only a percentage of the containers are destined to move by train. Once they arrived to the rail yard, a different pool of trucks move the containers into the train.

RESULTS

From running the simulation model according to the parameters described above the following results for the port operations, which demonstrate the normal behaviors for the containers ships arriving to the ports.



	Panamax	PostPanamax	SuperPostPanamax
Avg	2.45	5.46	1.98
Max	12.45	70.87	59.67
Min	0.00	0.45	1.23

Chart 11 Dwell Time for Vessels

The graphic shown above depicts the dwelling time for the different types of vessels, this represents the amount of time a type of ships spends idle while waiting for an available berthing position that meets its needs.

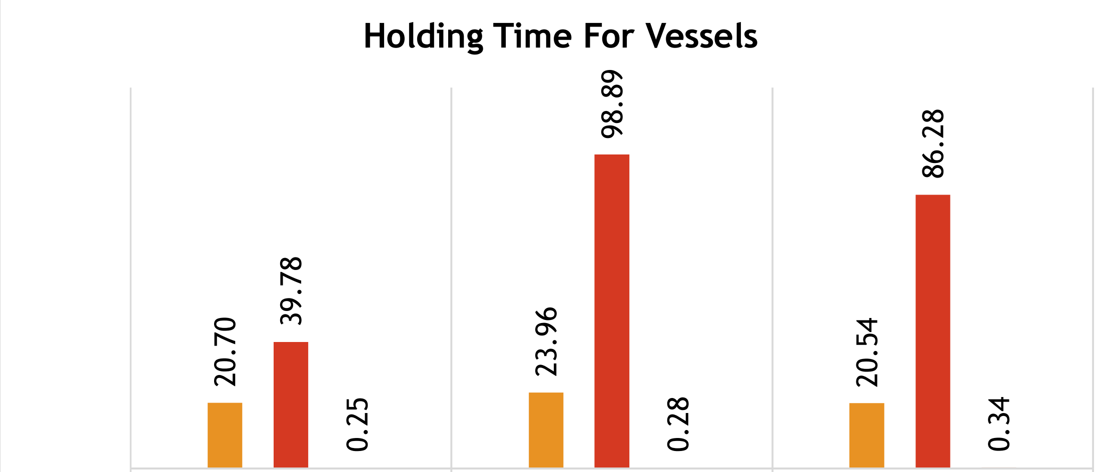
There are very low averages for the dwelling times because the mix of ships arriving to the port call table is very diverse. This means that in one day there are multiple types of ships arriving from Panamax to Super Post Panamax. Remember the different type of vessels have different berthing needs, therefore a Panamax can be berthed at any position, a Post Panamax can only berth at Post Panamax and Super Post Panamax berths and a Super Post Panamax can only berth at Super Post Panamax berths.

With the previous assumptions, the logic is that if there are any ships available to berth at their position they will gain priority over other ships with less priority, this states that if a

Panamax and Post Panamax are waiting for a Post Panamax Berth, the Post Panamax vessel gains berthing priority over the Panamax vessel.

This is the cause for the low average dwelling time ranging from 1.98 hours to 5.46 hours, this rise in the difference is exclusively to Post Panamax ships which most of carriers are using to this date because of the economic benefits. With the Panama Canal Expansion the expected trend is an increase in Super Post Panamax vessels arriving in the near future.

The Max values can be easily explained as for the busiest days of operations in which there is a broader arrangement of ships arriving than others days. The service times for those vessels are quite lengthy.



	Panamax	PostPanamax	SuperPostPanamax
Avg	20.70	23.96	20.54
Max	39.78	98.89	86.28
Min	0.25	0.28	0.34

Chart 12 Holding Time for Vessels

The graphics above show the normal behaviors of the loading and unloading times for the vessels. In this case the averages for the unloading of the vessels ranges from 20.54 to 23.96 hours. This means that in average a vessel stays a little bit less than a day in the port being unloaded.

This data has been validated with some quay crane operators of the Panama Ports Company, this is due that the vessels is unloaded with man operated quay cranes, which have an loading and unloading average of 30 movements per hour. A movement can refer to either one-40 feet container, two-20 feet containers or one-20 feet container. And from our understanding most of the containers unloaded from vessels are 40 feet containers. So the vast majority of this movements are probably unloading single containers at the time making the unloading operation such and arduous task.

Also the berthing positions have a fixed number of quay cranes which can operate in the vessel at the time this limits the number of quay cranes that can be used if there is only one vessel berthed.

VALIDITY, EXTENDABILITY AND OTHER THOUGHTS

Certain aspects of the model were simplified or not simulated. In this section there is a run-through over these various points in order to provide a clear perspective on where the model excels and where there is a great opportunity to extend or refine the results. The model, according to our interviews with the different component owners of the system, is at least a good representation of how the different components of the intermodal system interact with each other.

On the port block's throughput:

- In the model, implementing more berthing positions and classification on ship lengths and widths would yield results more accurate. The present results, though, show that **the port with the actual resources is very capable of providing the rail block with enough input to get the system running without interruption** or lags. It is understood that if the port uses as many trucks as declared on interviews (35-40+) and customs delays happen within the load time of the rest of one train, then **the port's throughput will always be equal or greater than the rails throughput**, effectively moving the bottleneck into a component of the rail system.

On track assignments, RTGs and top loaders and the shifting bottlenecks:

- The loading logic, planning, order and parking of the trains affects the system greatly but optimizing this in the Balboa side would not yield more throughput than what MIT can process in a day. Therefore, any improvements into the system have to be analyzed as a whole, taking into account the following:
    - o Truck availability is only as good for as many RTGs and Top Loaders we can put to work at the same time. More trucks will counter the effect of the customs delay and also will reduce the "next truck ready to load" time, so a balance should be achieved such that the RTGs and top loaders are not starved. In our runs, this balance was achieved at around 60 trucks. It is important to know that this increase will allow the RTGs and top loaders to work at their full potential, reducing the total load time and the amount of trains loaded in Balboa. Nevertheless, this is only as good for as many trains MIT and Cristobal could process.

- The number of RTGs and top loaders can be increased to obtain more throughput. However as mentioned in the previous point, a similar increase in processing capacity has to be implemented in MIT and Cristobal.
- Any increase in throughput should be quantified economically by the amount of TEUs in excess the system is now processing. For instance, one more train per day gives us 200 TEU which should be transformed into cost and compared with the investment of the Trucks, an RTG or a top loader.
- Currently, the system caps on 1040 Containers moved, or 5-7 trains daily depending on the amount of resources. Theoretically, the system has more throughput since we should take into account that Cristobal should add a 30% increase in throughput on the Atlantic Side. As far as it is understood, the amount of cargo that goes to Cristobal is less than that, negating this improvement since the track shouldn't be used for trains not loaded with cargo for Cristobal. Further studies should be done to determine how much of the cargo goes to Cristobal and how much it helps alleviate the bottleneck in the Atlantic side.
- It is interesting to also mention that according to these runs, there wouldn't be more benefits in adding a track into the Balboa rail yard without first adding service capacity in the Atlantic side. This leads to the conclusion that logically the system is capped by the part of the system with the least throughput. In our simulation runs, the least throughput component was observed in MIT so only a marginal benefit would come from optimizing one leg of the system, it would still be capped. Like mentioned before, a holistic view of the rail system and its components would be the best strategy to increase the total throughput of the transshipment operation.

On Southbound load and Cristobal Traffic

- It is important to remark that southbound operation times are taken into account even though southbound cargo is not present in the system. The time it takes in MIT to load the train, and the time it takes in Balboa to unload the train is been taken into account and affects both resources and timing of when the trains can be loaded or depart. So southbound loading times, unloading and resource utilization is being simulated, but the simulation of containers going southbound was not represented in the model. Since these mentioned times are been taken into account, if southbound operations were implemented in the model, the results should not shift too far away from what is presented in this report.
- Cristobal traffic, according to our interviews and data, is a small part of the system and all the trains are usually loaded for just one port. It is one of our assumptions that MIT is the gross of the traffic and of both the loading and unloading operations. It is much recommended to implement this track into the system, but since there is

no visibility on these assets it should be well documented before implementing it. Just as stated before, there shouldn't be an increase of more than 30% in the throughput of the Atlantic servers but these benefit would be only as good as the percentage of cargo that goes to Cristobal in comparison with the total cargo sent presently.

FUTURE STEPS

As the project had a limited availability of time, the team had several ideas for the model that due to these limitations could not be fully implemented. These ideas have some work done or are still in a concept stage. Below is a list of these other initiatives that can be pursued by future researchers:

- Capturing and collecting real data to create a better input thus increasing the quality and accuracy of the results
- Adapting the train unloading and loading logic so that the operations could be simulated in the northbound and southbound senses
- Obtaining the correct data regarding container priorities and deadlines and implementing it in the model
- Simplify the routing logic for some of the train elements in order to make it easier to change train destinations
- Adding a 3D background of the actual ports and railways to the model
- Importing better animations for the simulation elements such as: more dynamic RTG's, improved train loading/unloading movements, more detailed vessels as in type and size

CONCLUSIONS

After simulating the northbound operations of the train system many insights that help understand mainly the operations in Balboa were acquired. Parallel loading is substantially more beneficial to loading operations in Balboa than it is to dedicate loading resources to a single track and then continue with the next one. An increase in throughput of containers per day of 189 which translates into a 24% increase was observed. For the purpose of scenario analysis, the baseline scenario adopted parallel loading as the loading logic as this is the logic in real life operations.

Most of the results obtained from the different scenario analyses run were predictable. Adding loading resources such as RTGs, top loaders and trucks increased the throughputs of the northbound system. As presumed, removing loading resources decreased the throughput of the system except when an RTG was removed. It can be inferred that there was an insignificant change in the throughput when an RTG was removed because the trains reduced the use of track 2 west which is exclusively served by RTGs and increased the use of track 1 which is exclusively served by top loaders.

Having 60 trucks in the Balboa train operations provided an increase of 7% in the throughput of the northbound train operations. It was determined that 60 trucks in Balboa is the limit where adding more trucks does not provide any more benefits. Having five RTGs provided an 8% increase in throughput (increase of 76 containers per day) whereas having three RTGs did not cause a noticeable impact on the operations. Having five top loaders accounted for a 6% increase in the throughput (increase of 60 containers per day) meanwhile having three top loaders decreased the throughput by 4% (decrease of 32 containers per day).

Track utilization analysis helped determine that Balboa should prioritize the use of Track 2 East. The reason for this is because track 2 east has the highest amount of loading resources since it shares resources with track 2 west and track 1. If all loading resources are dedicated to each track a train can be loaded completely in just half an hour in track 2E, 45 minutes in track 1, and an hour in track 2 west. Clearly, track 2 east needs to be the primary track.

The whole intermodal system acts as an unceasing process. Vessels arrive with containers on one side and are transported to vessels on the other side. There are different stations such as quay cranes in Balboa, port trucks, rail trucks, loading resources in Balboa, loading resources in Colon and other elements that compose the system. Looking at this from the process improvement perspective, bottlenecks currently linger in any of these stations. If a bottleneck is alleviated, it will be transferred to the next slowest station. The stakeholders have to adopt a continuous process improvement mentality so that the train operations are sufficiently efficient to satisfy their customers’ demands.

Certain questions arise from the previously mentioned statements. Is it worth purchasing a new top loader or an RTG, training personnel and paying an extra salary for an increase of 60 containers transported per day? What are the benefits that the stakeholders receive from increasing the loading resources? These questions may only be answered by further analyzing the system and looking at the system as a whole. Consequently, it is imperative to include the southbound operations in the simulation so that the real limitations of the whole system are addressed.

This project's result is a fairly complete and complex simulation that suggests and encourages further study on the previously mentioned points. At the same time this study leaves as legacy a robust building block for simulating transshipment systems in Panama or similar operations elsewhere.

APPENDIX A– STAKEHOLDERS

GEORGIA TECH PANAMA LOGISTICS INNOVATION & RESEARCH CENTER

The Georgia Tech Panama Logistics Innovation and Research Center located in Panama City, Panama is one of the latest additions to the Georgia Tech Supply Chain & Logistics Institute (SCL). Under an agreement negotiated with the Panama's National Secretariat of Science, Technology and Innovation (SENACYT), the SCL operates this unique research and education Panama Center focused on logistics and trade. The center has three core thrusts: applied research, education, and competitiveness. The strategic objectives of the centers are to improve the logistics performance of the country and to aid in developing the logistics and trade capabilities that will enable Panama to become the trade hub of the Americas.[3]

MANZANILLO INTERNATIONAL TERMINAL (MIT)

MIT started operations on April 16, 1995 at a location near the Atlantic opening of the Panama Canal immediately adjacent to the Colon Free Trade Zone (CFZ). MIT offers efficient and reliable port services to shipping lines transiting the Panama Canal or serving the South America and Caribbean Region. MIT has direct access into the CFZ and highway access to the cities in the Republic of Panama and other Central American countries.[4]

PANAMA PORTS COMPANY (PPC)

Since 1997, Panama Ports Company (PPC) is in charge of managing two ports, one on each side of the Panama Canal. The Port of Balboa is located in the city of Panama (Pacific Ocean) and the Port of Cristobal, in the city of Colon (Atlantic Ocean). The company began operations in Panama through a 25-year extendable concession granted by the government (Law 5 of January 16, 1997) for the administration of both ports.

PANAMA CANAL RAILWAY COMPANY (PCRC)

Panama Canal Railway Company (PCRC) is the only railway operator in the country. The train was built in 1855 permitting travel between the Pacific and Atlantic oceans by traversing the Panamanian Isthmus. This feature earned it the title of first transcontinental railroad in the world. In 1998, Mi-Jack Products and Kansas City Southern invested in PCRC as a joint venture. Both companies helped to fully restore the rail system by 2002. The railroad is side connected at the Pacific with the Port of Balboa allowing loading and discharging of containers bound to the Atlantic terminals of Cristobal

[3] www.gatech.pa
[4] http://www2.mitpan.com

and MIT. After discharging in MIT and Cristobal, the train is loaded with containers that are bound to Balboa. The terminal of Cristobal allows the embarking of passengers and loading of containers with an in-dock service.

According to the PCRC statistics, 2,000 containers are transferred on average per day in both directions for a yearly throughput of about 650,000 units. The trip is about 76 kilometers and 1 hour and 15 minutes traveling time between terminals with typically 10 trips daily in each direction for double stack trains based on container demand. A set of 6 passenger cars are used during weekdays under fixed schedule mainly for tourists and executives travelling from Panama City to Colon Free Zone. The maximum handling capacity of the service has been estimated in 2 million containers per year.[5]

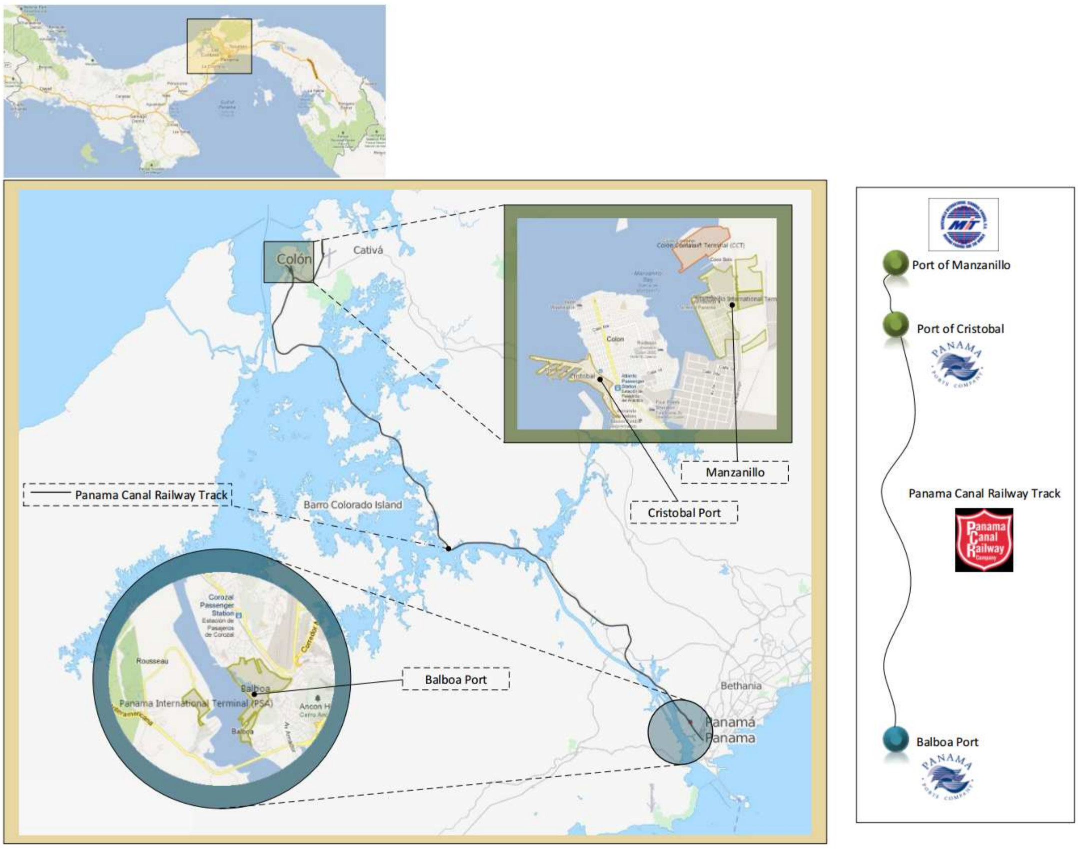


Figure 6 - System Map and Stakeholders' Location

[5] http://www.panarail.com

APPENDIX B – SIMULATION ILLUSTRATIONS

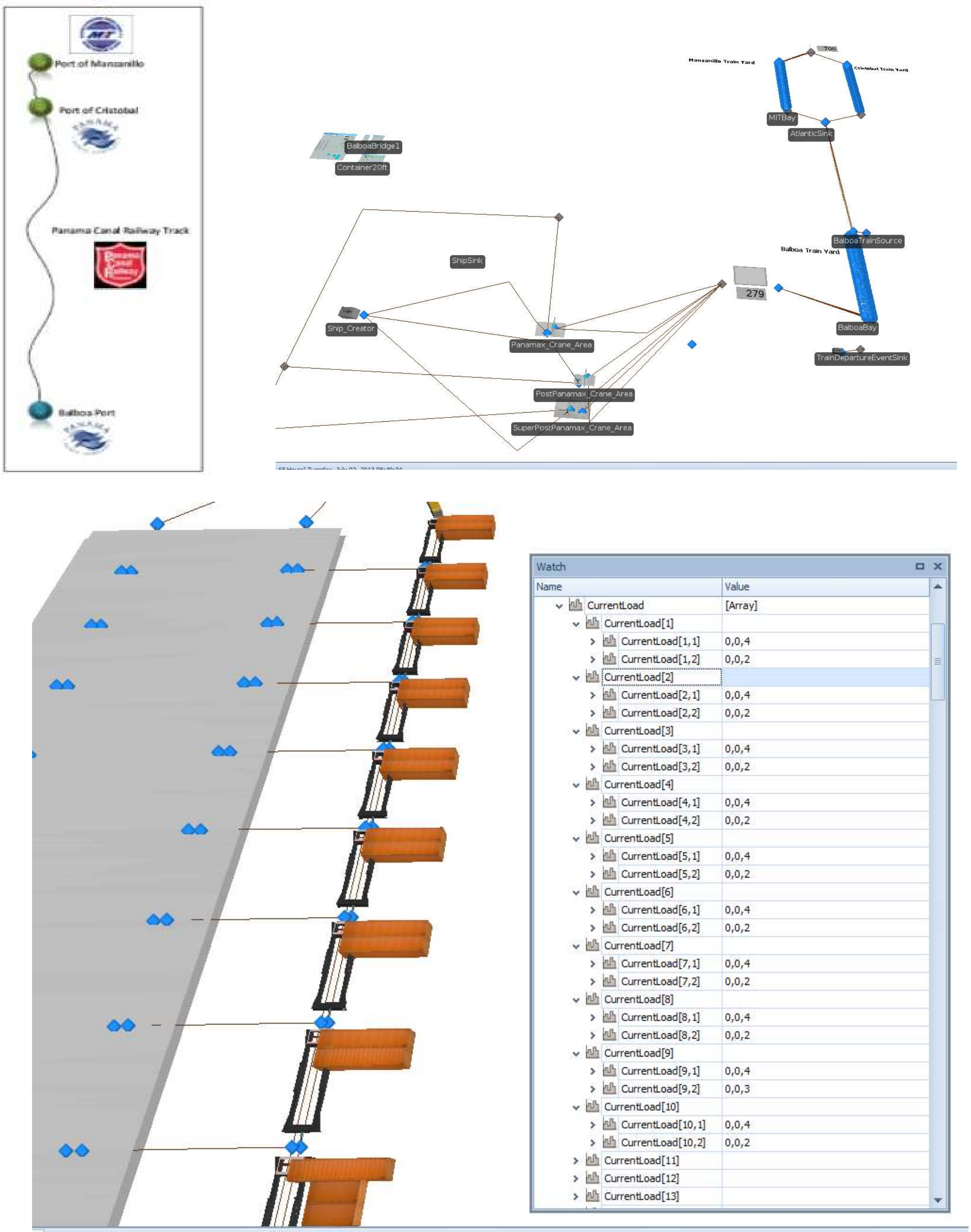


Figure 8 - Balboa Tracks and Current Load Tracking

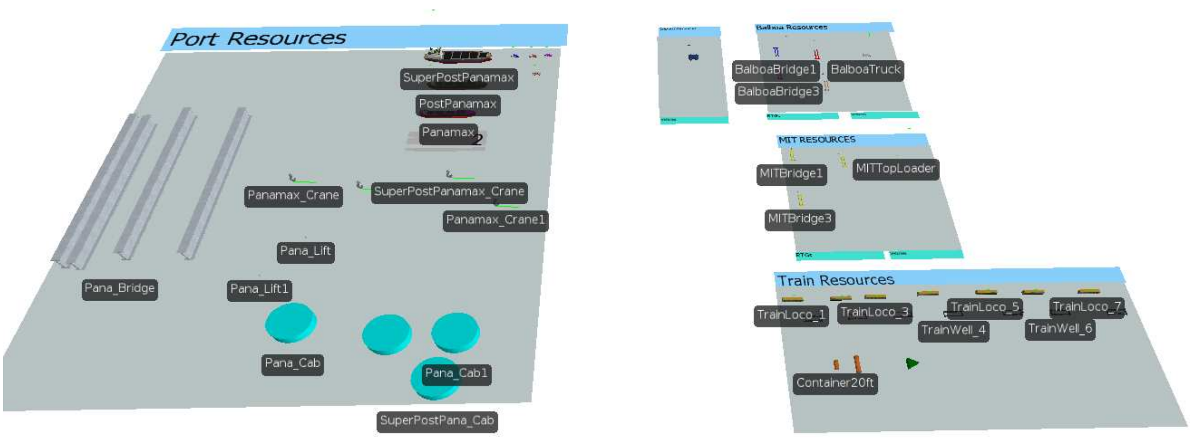
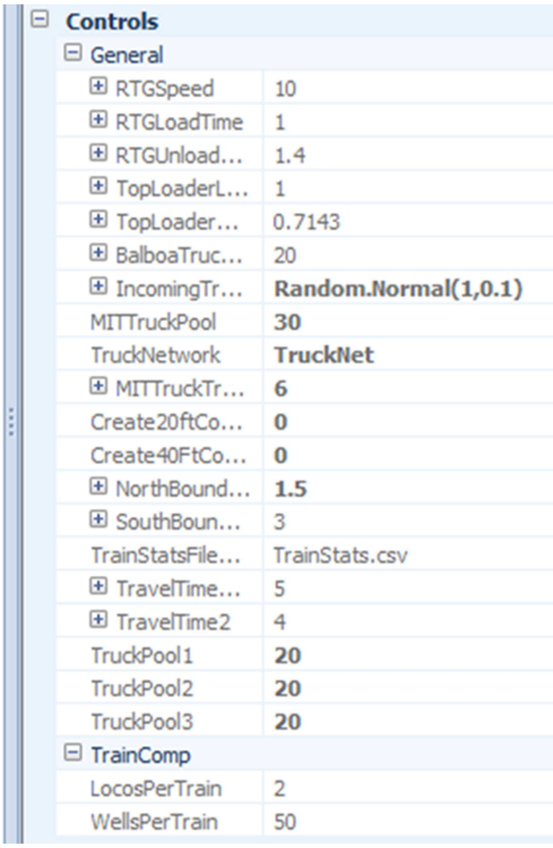


Figure 9 - Model Resources

Initial_Sequence | Port Calls | Vehicle Sink Route | Vehicle Sink Panamax | Vehicle Sink Super PP

	Ship Type	Ship Size	Container20ft	Container40ft	Date Time
8	PostPanamax	4301	0.25	0.75	07/01/2013 16:00:00
▸ 9	SuperPostPanamax	4711	0.4	0.6	07/01/2013 18:...
10	PostPanamax	3400	0.1	0.9	07/02/2013 11:00:00
11	SuperPostPanamax	8567	0.4	0.6	07/02/2013 11:00:00
12	SuperPostPanamax	5123	0.3	0.7	07/02/2013 11:00:00
13	SuperPostPanamax	5123	0.4	0.6	07/03/2013 11:00:00
14	PostPanamax	2580	0.2	0.8	07/03/2013 11:00:00
15	PostPanamax	2580	0.4	0.6	07/04/2013 11:00:00
16	Panamax	2331	0.2	0.8	07/04/2013 11:00:00
17	PostPanamax	2556	0.4	0.6	07/04/2013 11:00:00
18	PostPanamax	2556	0.3	0.7	07/05/2013 11:00:00
19	PostPanamax	3059	0.4	0.6	07/05/2013 11:00:00
20	SuperPostPanamax	5087	0.3	0.7	07/05/2013 11:00:00
21	PostPanamax	4366	0.4	0.6	07/05/2013 11:00:00
22	PostPanamax	4366	0.4	0.6	07/05/2013 11:00:00

Figure 10 – Sample of Port Calls Table



Controls	
General	
RTGSpeed	10
RTGLoadTime	1
RTGUnload…	1.4
TopLoaderL…	1
TopLoader…	0.7143
BalboaTruc…	20
IncomingTr…	**Random.Normal(1,0.1)**
MITTruckPool	**30**
TruckNetwork	**TruckNet**
MITTruckTr…	**6**
Create20ftCo…	**0**
Create40FtCo…	**0**
NorthBound…	**1.5**
SouthBoun…	3
TrainStatsFile…	TrainStats.csv
TravelTime…	5
TravelTime2	4
TruckPool1	**20**
TruckPool2	**20**
TruckPool3	**20**
TrainComp	
LocosPerTrain	2
WellsPerTrain	50

Figure 11 - Controls for the Model Parameters

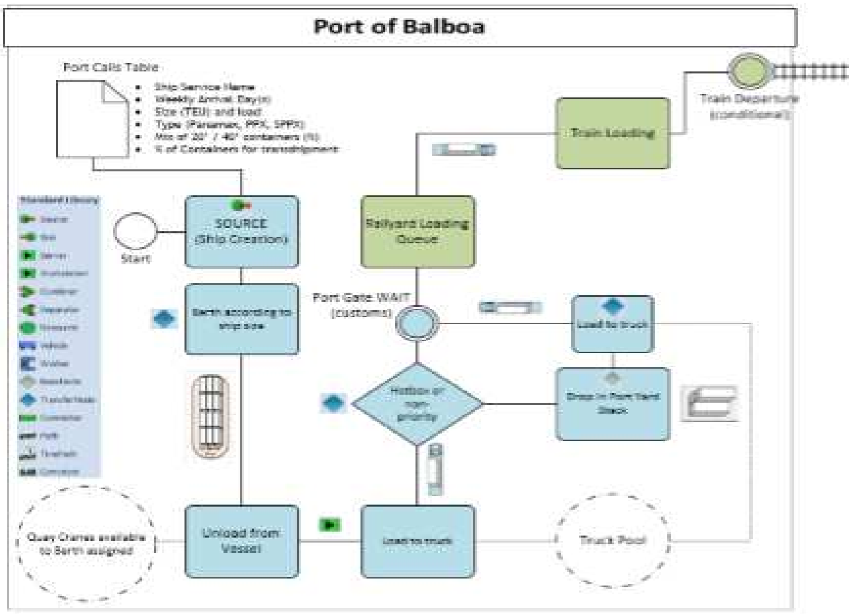


Figure 12 - Port of Balboa Block Diagram

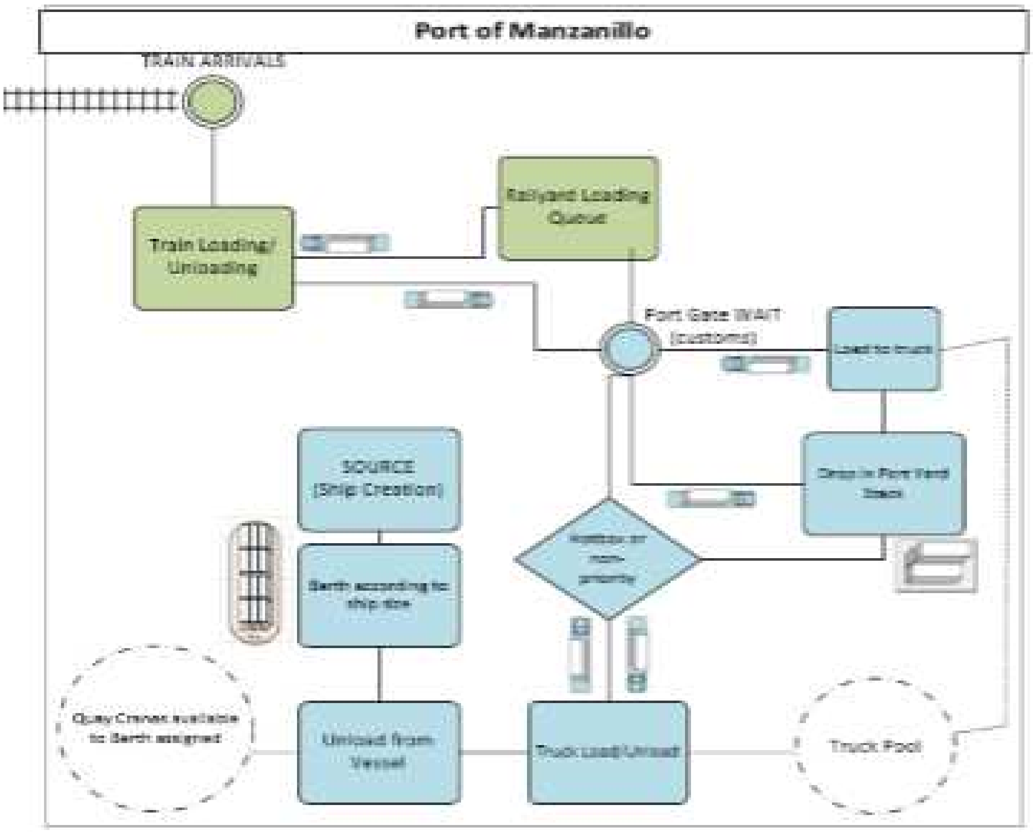


Figure 13 - Port of Manzanillo Block Diagram

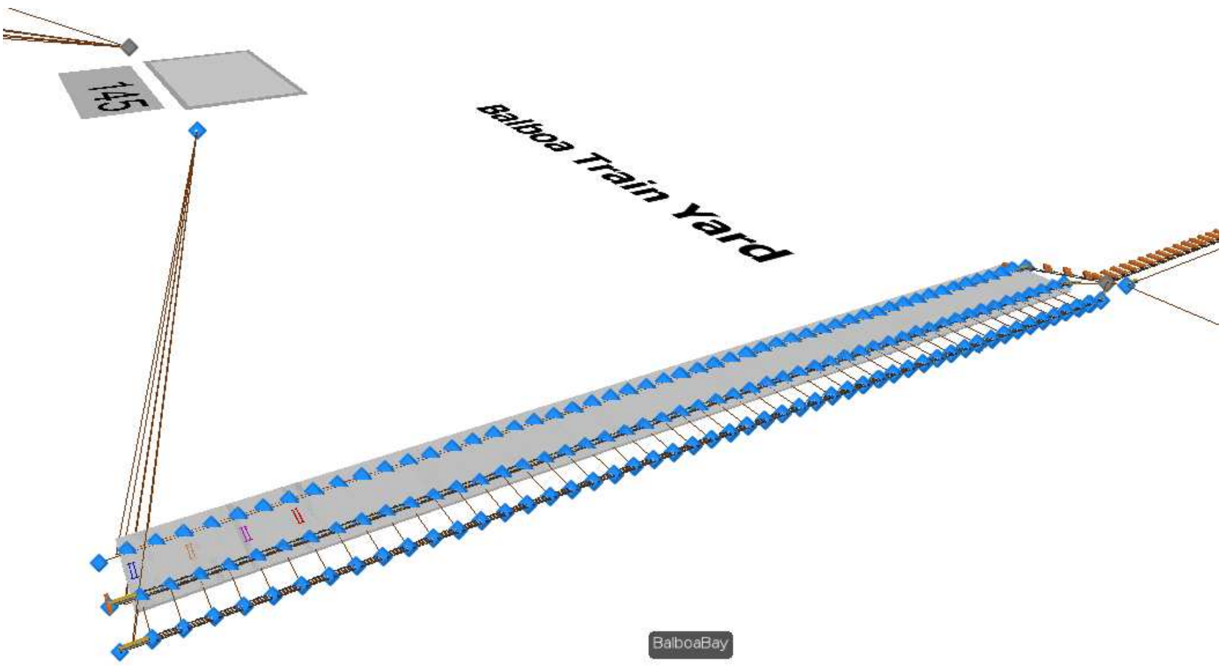


Figure 14 - Tracks in Balboa and stack with a counter on current load.