A SIMULATION MODEL FOR DETERMINING CONTAINER THROUGHPUT AT AN EXPANDING SEAPORT

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Abstract This paper presents a simulation model to determine the container throughput of a seaport that is under construction. Included in the paper are a description of the container terminal, a description of the simulation model and an analysis of the simulation results. The simulation model was written in ProcessModel and included five submodels that run independently of each other. Data are passed between the submodels by global variables. In addition, a number of attributes are assigned to the entities. These variables and attributes control entity movement, branching and activity operations. The simulation results indicated that the goal of 325,000 containers annually is feasible with the proposed design parameters.

1 Introduction

Over ninety percent of cargo currently transported worldwide is shipped as containerized cargo [10]. For example, in 2000, container port traffic for selected ports in the U.S. was:

- Los Angeles 4,900,000 TEUs (twenty foot equivalent units)
- Long Beach 4,600,000 TEUs
- Charleston 1,600,000 TEUs
- Houston 1,100,000 TEUs
- Savannah 900,000 TEUs

As supply chains become more global and the use of containerized cargo increases, the ports throughout the U.S. are improving operations and undergoing major expansions. The Alabama State Port Authority is currently enhancing container and intermodal operations at the Alabama State Docks in Mobile, Alabama. Figures 1 and 2 are renderings of the facility that is currently under construction. The shipping terminal will include 92 acres with 2,000 feet of berthing space dredged to a depth of 45 feet for two berths. A grade-separated roadway will connect the container terminal with an intermodal terminal and value added warehousing and distribution area. The container operations will be able to accommodate unit container trains that will pick-up or off-load containers from the terminal warehousing and value-added areas. Trains up to 8,000 feet in length will be able to serve the facility without blocking rail traffic on the main line.

Figure 1. Rendering of container terminal and intermodal facility

Figure 2. Rendering of container unloading and loading

2 Research Objective

The focus of this research was to determine the container throughput given a predefined set of operation parameters. The design goal for the container terminal is 650,000 TEUs annually. A forty-foot container is equivalent to two TEUs. Therefore, the design goal equates to 325,000 containers, about 220,000 containers unloaded and 105,000 containers loaded annually.

3 Previous Research

A prior study on the container terminal expansion at the State Docks in Mobile focused on the utilization of resources [3]. This study found that the utilization of resources were quite low and did not present a problem in container throughput.

Hassan [4] has written an overview of port simulations. A port operations simulation model has been written in C to address multiple port functions, various ship arrival patterns, and coordination between terminals in more that one port [5]. Demirci [1] developed a flexible, interactive simulation model for container terminals. The model has been used for evaluating port design, port planning, capacity increases and productivity enhancements. Ramani [14] also has developed an interactive simulation model to study container operations. The model provides estimates for port performance and operating strategies for logistics planning of container operations.

Rida, et al. [15] developed a simulation model of the Casablanca container terminal. The model was used as a decision assistant for real time decision making. SimSea is a simulation model of ocean container carrier operations [20]. Included in the model is logic for loading and unloading containers from vessels, vessel transport between ports and container transport from the ports to the customers. The model also includes transporting empty containers to compensate for imbalances in the flow of containers.

A decision support system for management of an intermodal container terminal has been developed for resource allocation and scheduling of operations [2]. The simulation tool has been used to introduce new operational approaches.

Merkuryev, et al. [9] developed a simulation model of the Riga harbor container terminal that is the largest container terminal on the Baltic Sea. Tugeu [19] developed a simulation model of the Istanbul seaport. The model was used to evaluate various investment plans. Tahar and Hussain [17] have developed a simulation of the Kelang container terminal. Shabayek and Yeung [16] have developed a simulation for the Kwai Chung container terminals in Hong Kong.

Yun and Choi [21] developed an object oriented simulation model to analyze container terminal operations. Legato and Rina [8] developed a simulation model to assist in the berthing plan and resource optimization at a container terminal. Thiers and Janssens [18] have also developed a port simulation model for decision making.

Itmi, et al. [6] developed a simulator regarding a container terminal. Pater and Teunisse [12] have developed a methodology for simulation large container facilities such as at Rotterdam. Leathrum and Frith [7] and Nevins, et al. [11] have been developing a simulation model for loading and unloading military cargo from ships including containers and wheel vehicles.

4 Simulation Model

Figure 3 presents the conceptual framework of the container terminal model. The model consist of five submodels:

- Ship unloading and loading of containers – ship entities
- Train unloading and loading of containers – train entities
- Truck unloading and loading of containers – truck entities
- Movement of containers from dock to container yard – move order1 entities
- Movement of containers from container yard to dock – move order2 entities

These submodels run independently of one another, each with a different entity type. Data are passed between the submodels by a number of global variables. In addition, a number of attributes are assigned to the entities. These variables and attributes control entity movement, branching and activity operations. The simulation model was written in ProcessModel [13].

The global variables are:

- Total containers unloaded from ships
- Total containers unloaded from trains
- Total containers unloaded from trucks
- Total containers loaded onto ships
- Total containers loaded onto trains
- Total containers loaded onto trucks
- Containers in terminal yard from ships
- Containers in terminal yard from trains and trucks
- Containers on dock from trains and trucks
- Containers on dock from ships

The terminal model has two container storage areas. One area is for the storage of containers from ships that are to be loaded onto trains and trucks. The second area is for the storage of containers from trains and trucks that are to be loaded onto ships.

The model simulates the unloading and loading of containers one at a time. Consequently a number of counters, or global variables, are incremented and decremented based on the model logic. The ProcessModel label boxes are used to display the content of these counters during the simulation. For example, a container is unloaded from the ship and placed on the dock. A counter is incremented by one. The submodel Movement of Containers from Dock to Container yard will decrement the counter by one, move the container to the container yard and increment the counter by one.

The model utilizes a small yellow container entity shaped like a rectangle. As a container is unloaded, loaded or moved, the movement of the container entity is shown on the computer.

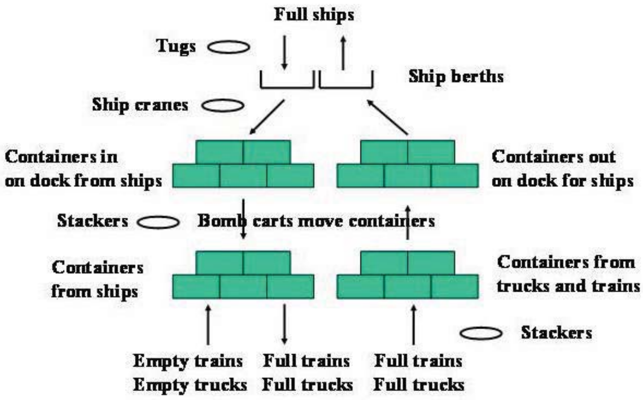

Figure 3. Conceptual framework of simulation model

5 Baseline Run1

The baseline Run1 consisted of the following inputs:

- Time between arrivals: three days for ships, two days for trains and two hours for trucks; two days for empty trains with no containers, two hours for empty trucks
- Arrival capacity: ship triangular distribution T(400,500,600) containers, train T(80,100,150) containers and truck 1 container
- Departing capacity; ship T(100,150,200) containers, train T(80,100,150) containers and truck 1 container
- T(15,20,30) minutes for tug to position or remove ship at berth
- Two minutes for crane or stacker to unload or load a container from ship, train or truck and two minutes for stacker to load or unload a container at ship dock or a container yard
- T(4.5,4.0,5.5) minutes for bomb cart to move a container from ship dock to the container yard or from a container yard to the ship dock
- Two ship berths, two ship cranes and two tugs
- Ten slots for trucks to unload at a time and ten slots for trucks to load at a time
- Two slots for trains to unload at a time and two slots for trains to load at a time
- Ten carts for loading and moving containers simultaneously from dock to container yard and ten carts for loading and moving containers simultaneously from container yard to dock
- Eight stackers shared for unloading and loading bomb carts, trains and trucks

The simulation started empty and idle; no ships, trains or trucks were initially at the terminal; and the container yard was empty.

6 Verification and Validation

Model verification consists of determining if the model is correctly represented in the simulation code. Model validation consists of determining if the model is an accurate representation of the real world system. ProcessModel has a Label block that displays data from the global variables during the simulation. By slowing down the simulation it is possible to observe these values as entities move through the simulation. As part of the model verification, the containers unloaded from ships minus the containers loaded onto trains and trucks minus the containers on dock unloaded from ships equals the containers in yard from ships. The containers unloaded from trains and trucks, minus the containers loaded onto ships, minus the containers on the dock waiting to be loaded onto ships equals containers in the yard from trains and trucks.

Model validation was not possible since the container terminal is under construction. However, it was possible to use data from the existing container facility for the service times. A team of individuals that were familiar with the operations of the existing terminal was assembled to visually observe the operations of the terminal during the simulation.

7 Experimental Design

Table 1 shows the experimental design. The research objective was to determine the container capacity of the terminal. Therefore, the logical variable was the time between arrivals of the entities. Since the capacity for a truck was only one container, the time between arrivals for full and empty trucks was kept constant at two hours. All other data remained the same as the baseline.

	Time between arrivals		
	Ships	**Full trains**	**Empty trains**
Run1	3 days	3 days	3 days
Run2	3 days	2 days	2 days
Run3	3 days	1 day	1 day
Run4	3 days	12 hours	12 hours
Run5	2 days	3 days	3 days
Run6	2 days	2 days	2 days
Run7	2 days	1 day	1 day
Run8	2 days	12 hours	12 hours
Run9	1 day	3 days	3 days
Run10	1 day	2 days	2 days
Run11	1 day	1 day	1 day
Run12	1 day	12 hours	12 hours
Run13	1 day	6 hours	6 hours

Table 1. Experimental design

8 Analysis

Tables 2 and 3 give the container activity for each run of 1,440 hours. The table includes the number of containers that were unloaded from ships, trains, and trucks; containers that were loaded onto ships, trains and trucks; containers that were in the container yard at the end of the simulation; and containers that were on the dock unloaded from ships or ready to be loaded on ships from trains and trucks.

	Run1	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**
In from								
Ship	10,141	10,169	9,922	10,322	10,498	13,505	14,772	15,502
Train	2,291	3,309	6,506	13,440	2,166	3,242	6,762	13,269
Truck	720	720	720	720	720	720	720	720
Out on								
Ship	2,861	3,015	2,828	2,960	2,850	3,846	4,632	4,329
Train	4,231	6,386	8,500	8,894	4,153	6,196	12,443	13,988
Truck	1,440	1,440	1,422	1,428	1,440	1,440	1,440	1,440
In yard from								
Ship	4,470	2,343	0	0	4,905	5,869	889	74
Train/truck	0	0	0	0	0	0	0	0
On dock from								
Ship	0	0	0	0	0	0	0	0
Train/truck	150	1,014	4,398	11,200	36	116	2,850	9,660

Table 2. Container activity for Runs1-8 (Runs of 60 days)

	Run9	Run10	Run11	Run12	Run13
In from					
Ship	10,857	14,489	24,172	29,995	29,961
Train	2,160	3,219	6,332	13,537	26,381
Truck	720	720	720	720	720
Out on					
Ship	2,756	3,918	7,047	8,688	8,871
Train	4,134	6,274	12,465	25,172	28,433
Truck	1,440	1,440	1,440	1,440	1,440
In yard from					
Ship	5,283	6,775	10,267	3,380	85
Train/truck	0	0	0	0	0
On dock from					
Ship	0	0	0	0	0
Train/truck	124	21	5	5,569	18,230

Table 3. Container activity for Runs9-13 (Runs of 1,440 hours)

Table 4 gives the entity throughput and the average time each entity was at the terminal. At the bottom of the table are the average value added times for each entity type at the terminal. The difference between the average entity times and the value added times could be attributed to various delays or time waiting for a resource or containers. This time difference can be consider as non-value added time or wasted time and consequently should be minimized.

	Ships	Ship time (min)	Trains	Train time (min)	Trucks	Truck time (min)
Run1	19	4,942	40	524	1,440	24
Run2	20	2,124	60	514	1,440	24
Run3	20	1,979	82	13,901	1,422	126
Run4	20	2,055	87	26,984	1,428	100
Run5	19	17,916	40	509	1,440	24
Run6	25	7,305	60	501	1,440	24
Run7	30	2,005	120	523	1,440	24
Run8	30	2,046	135	18,755	1,440	67
Run9	19	28,962	40	507	1,440	24
Run10	27	25,273	60	504	1,440	24
Run11	47	10,240	120	493	1,440	24
Run12	59	2,005	239	518	1,440	24
Run13	59	2,013	267	19,956	1,440	24

Table 4. Entity throughput and average times at terminal (Runs of 1,440 hours)

The average value added times excluding any delays or waiting for resources were ships, 1,350 minutes; trains, 330 minutes; and trucks, 13 minutes. Runs 2, 7 and 9 had entity times in the terminal that were the closest to value added times.

Table 5 gives the utilization of resources for each run after 1,440 hours. The large utilization of the ship berths for Runs5, 6, 9, 10, and 11(ranging from 86 to 99 percent) can be attributed to the long times that the ships are at the terminal waiting for containers to load. For these runs the time between arrivals for ships decreased without a corresponding decrease in the time between arrivals for trains.

	Ship berths (2)	Ship cranes (2)	Tugs (2)	Carts (20)	Stackers (8)
Run1	56	22	1	8	12
Run2	23	22	1	9	14
Run3	22	22	1	10	18
Run4	23	23	1	15	26
Run5	97	23	1	8	12
Run6	86	30	1	11	16
Run7	33	33	1	14	23
Run8	34	34	1	18	31
Run9	99	23	1	8	12
Run10	99	32	1	11	17
Run11	97	54	2	19	28
Run12	67	67	2	28	44
Run13	67	67	2	36	59

Table 5. Utilization of resources (%)

Figure 4 is a graph of the average times that ships and trains were at the terminal, including value added and non-value added times. Figure 5 is a plot of the containers in, containers out and containers in the terminal at the end of the simulation run of 1,440 hours, or 60 days.

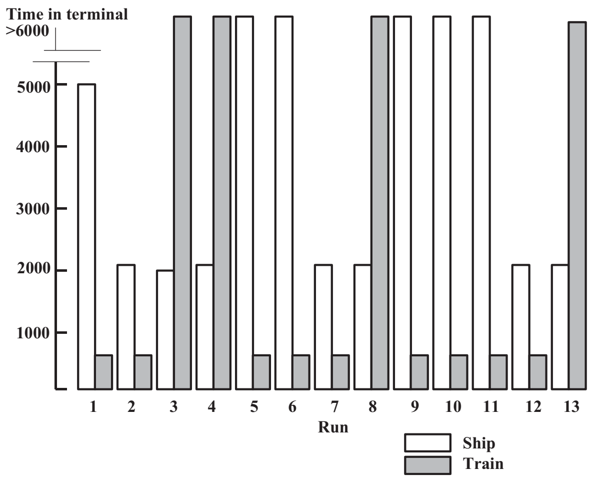

Figure 4. Average times at terminal

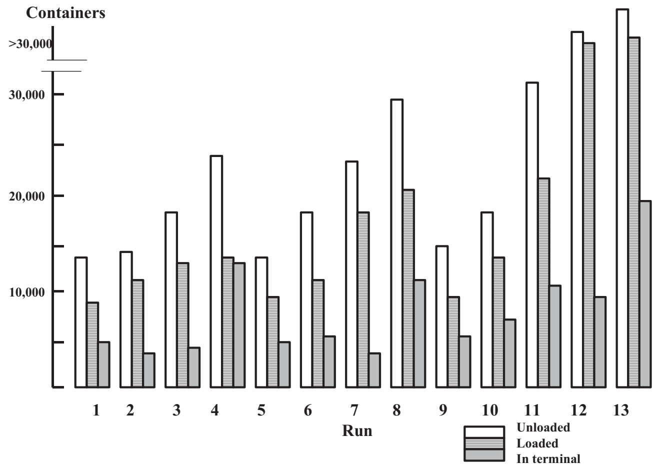

Figure 5. Container activity

Runs 2, 7 and 12 had low entity times in the terminal with minimum waiting times. Table 6 is a summary of these three runs. Run12 exceeds the container throughput objective of 220,000 containers unloaded annually and 105,000 containers loaded annually.

	Run2	Run7	Run12
Time between arrivals			
Ships	3 days	2 days	1 day
Trains (full)	2 days	1 day	12 hours
Trains (empty)	2 days	1 day	12 hours
Trucks	2 hours	2 hours	2 hours
Ships through	20	30	59
Ship time in terminal	2,124	2,005	2,005
Trains through	60	120	239
Train time in terminal	514	523	518
Trucks through	1,440	1,440	1,440
Truck time in terminal	24	24	24
Containers in annually	85,188	133,524	265,512
Containers out annually	65,046	111,090	211,800
Containers in terminal	20,142	22,434	53,712
Utilization			
Ship berths (2)	23	33	67
Ship cranes (2)	22	33	67
Tugs (2)	1	1	2
Carts (20)	9	14	28
Stackers (8)	14	23	44

Table 6. Summary for Runs 2, 7 and 12

9 Conclusions

In summary, the goal of 325,000 containers annually is feasible with the proposed design parameters. Run12 exceeded the goal and Run7 came close to the goal. To achieve this design goal the time between arrivals of ships must drop from three days for Run1 to one day and the time between arrivals of trains must drop from three days for Run1 to twelve hours. Increasing the entity arrivals had no impact on the entities time in the terminal.

For Run12 ships averaged thirty-three hours in the terminal, trains averaged nine hours and trucks twenty-four minutes. Again these times were well within the desired turn around times. Values added times were twenty-two hours for ships, five hours for trains and thirteen minutes for trucks. The differences in the times in the terminal and the value added times are the times waiting for containers, resources or activities.

Overall, utilization of resources is low. The model indicated a large buildup of containers in the terminal at the end of the simulation. For Run12 this buildup was 53,712 containers annually. It appears that this buildup will continue to increase as the simulation continues to run. This issue needs to be addressed with several additional runs of the model. For example, the container buildup from ships could be reduced with an increase of empty train arrivals. The container buildup from trains may point to an over arrival of container trains. One approach would be to reduce the time between arrivals of container trains while at the same time increasing the arrival of empty trains.

The model is very sensitive to the interaction of arrivals of ships and trains. For example, a decrease in the time between arrivals of ships may not necessary increase throughput if there are not adequate trains available to remove the containers from the terminal. The same holds for a decrease in the time between arrivals of trains.

Decreasing the time between arrivals of ships or trains may actually increase the time the entities are at the terminal. For example, a decrease in the time between arrivals of ships will result in a demand for more containers that are available to load on the ships. If there is not an adequate supply of containers arriving from trains, the ships will have to wait. As a result, the time the ship is in the terminal increases drastically. This point is reinforced in the selection of Runs2, 7 and 12 with overall low times in the system and large container handling. In these three runs a decrease in the time between arrivals of ships was also accompanied by a corresponding decrease in the time between arrivals of trains.

The utilization of resources was relative low. However, these low utilizations are misleading. For example when two ships are in port all berths are fully utilized as well as the cranes unloading the ships. Likewise, the carts moving containers from the docks to the container yard are probably fully utilized. In many instances resource utilizations drop to zero when ships leave the terminal.

The arrivals of full and empty trucks remained constant for all runs because of the capacity of one container per truck. The relative large buildup of containers in the terminal at the end of the simulation could possibly be reduced by an increase in the arrival of full and empty. Additional truck volume would also impact the truck traffic in the region and is an area for further research.

ProcessModel was adequate to addressing the stated research objective. The literature review indicated a number of models written in a programming language to solve more complex issues. The ProcessModel was developed in less than forty hours that included collecting the necessary input data. The ProcessModel label feature that allowed the displaying of container content through the terminal proved to be an excellent tool for not only V&V but also to observe the running of the model and the movement and buildup of containers.

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