

Evaluation of Truck Traffic at a Container Terminal Using Simulation

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ABSTRACT

This paper presents a simulation model to determine the impact of increased truck traffic entering and exiting the container terminal at the Alabama State Docks in Mobile, AL. Of special interest was the number of truck locations required to process the truck traffic and the possible use of trains to reduce the truck traffic entering and exiting the container terminal. Truck locations are used in the ProcessModel to control the maximum number of trucks in the container terminal. As a result, the number of truck locations is an important measure of the amount of space needed within the terminal. The Baseline Run1 had fifty trucks, or resources. Runs2-6 continually reduced the number of truck locations available. It appears that with the existing entity arrival rates only ten truck locations are necessary. The results with ten truck locations were identical to the results with fifty truck locations. The number of locations will probably have to increase if there is an increase in container traffic. The simulation results indicated that the container terminal would have a significant impact of truck traffic in and out of Mobile. A ship arriving every four days (or about seven ships a month) with an average of 450 containers for import and 350 containers for export will require about 350 trucks to bring in containers for export and another 450 trucks to move the incoming containers inland. This traffic volume will occur every four days, which is the time between arrivals of ships. Run3 estimated 4,400 trucks a month (or 220 per day) will be added to the interstate traffic in Mobile with the arrival of a container ship every four days. The addition of train service to the container terminal will reduce the truck traffic servicing the terminal. The simulation results for Run7 indicated at 18% reduction in truck traffic with a train arriving every five days. The arrival of a train every three days in Run8 had a 31% reduction in truck traffic. For every container that arrives on a train a truck is removed from delivering a container to the terminal. Also for every container that arrives on a ship and leaves the terminal on train a truck is removed from the Mobile road network. Included in this paper are a description of the simulation model, the experiment and an analysis of the simulation results.

KEYWORDS

Port, container terminal, intermodal, simulation

INTRODUCTION

Over ninety percent of cargo currently transported worldwide is shipped as containerized cargo (Moffatt & Nichol, 2002). As supply chains become more global and the use of containerized cargo increases, the ports throughout the United States are improving operations and undergoing major expansions.

The Alabama State Port Authority recently completed a major expansion of its container and intermodal operations at the Alabama State Docks in Mobile, Alabama. The shipping terminal includes 92 acres with 2,000 feet of berthing space dredged to a depth of 45 feet for two berths. A grade-separated roadway connects the container terminal with an intermodal terminal and value added warehousing and distribution area (Moffatt & Nichol, 2002). Figures 1 and 2 are two recent photographs of the new container terminal.

There is concern by various state and regional agencies of the impact of increased truck traffic on the interstate system in the Mobile area. Mobile is served by interstate I10 going east and west and interstate I65 north that originates in Mobile. The objective of this study was to evaluate the impact of increased truck traffic resulting from the container terminal. One option evaluated was the offloading of containers onto trains.



Figure 1. Container ship arriving at terminal



Figure 2. One of two ship cranes unloading container onto a cart

CONTAINER TERMINAL

Figure 3 is a sketch of the container movement at the container terminal located at the Alabama State Docks in Mobile, AL. Containers arriving on ships will depart on trucks. Likewise, containers arriving on trucks will depart on ships. Tugs escort the ships into a berth. Cranes unload and load the containers. The cranes unload containers onto chassis that move the containers to the container yard. Stackers unload the containers at the container yard. Likewise, stackers load containers at the container yard onto chassis for transport to the ship dock. Stackers unload containers from trucks at the container yard. Stackers also load containers in the container yard from ships onto trucks for export.

Three types of trucks arrive at the terminal. Trucks that arrive with a full container leave with no container. Trucks that arrive with no container leave with a full container. Also some trucks that arrive with an empty container leave with a full container. Interviews with the management of the docks indicated that upward of 95% of the trucks arrive and leave the facility in a condition different from their original condition, thus, few trucks arrive with a load and leave with a load. This is mainly due to the lack of a clearing house to inform potential logistics companies of opportunities to maximize loaded trips.

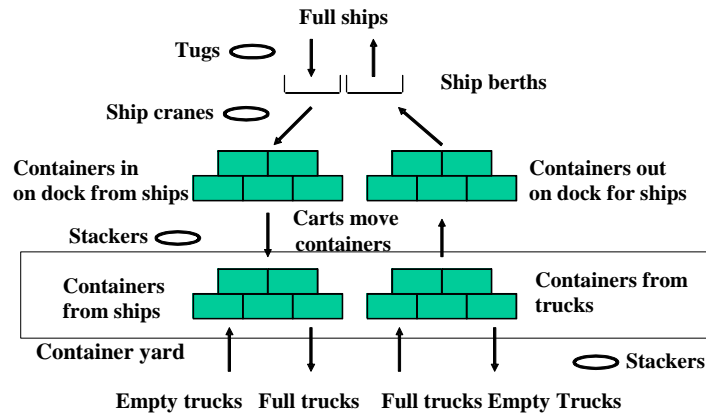


Figure 3. Overview of container model

SIMULATION MODEL

The ProcessModel (1999) used in this study was constructed following the conceptual framework developed by Schroer, et.al. (2008) consisting of a number of submodels that run independently. Each submodel has its own data input and entities with specific attributes. Data are shared between the submodels by global variables. The content of the global variables can be altered within any submodel with the new values immediately shared with any other submodel. These global variables can also be used in logic statements to control the movement and routing of entities, branching logic, and updating entity attributes.

The ProcessModel has the following submodels:

- Ship unloading and loading of containers
- Truck unloading and loading of containers
- Movement of containers from ship dock to container yard
- Movement of containers from container yard to ship dock

The terminal has the following resources: ship berths, ship cranes, truck locations, stackers, chassis and inspectors. The model has nine entity attributes, fourteen global variables, forty-six activity blocks and six entity blocks.

MODEL VERIFICATION AND VALIDATION

Model verification can be defined as determining if the model is correctly represented in the simulation code. Verification in ProcessModel was accomplished by eliminating all variation in the model and only using constants for all arrival times and service times. The times through the system could then be readily compared with the input data.

Model validation can be defined as determining if the model is an accurate representation of the real world system. ProcessModel has a Label block that displays data generated by the global variables during the simulation. By slowing the simulation down, it is possible to observe these values as the entities move through the simulation. A group of transportation experts were placed in front of the computer to observe the model operation and the peak hour volume moved through the system as designated by the input volumes.

EXPERIMENTAL DESIGN

The experimental design is provided in Table 1. Runs2-6 are identical to the Baseline Run1 with the exception of the number of ProcessModel resources allocated for truck locations. Trucks locations are defined as the maximum number of trucks permitted in the container terminal at a time and are critical in determining the amount of space for trucks within the terminal.

Run7 was defined after selecting the output from Runs2-6 with the smallest number of truck locations and without a decrease container throughput. Run3 was selected and then modified to include the arrival and departure of trains at the terminal. Run7 had a train arriving every five days. Run8 had a train arriving every three days. Since containers arrived and departed on trains for Runs7-8 the time between arrivals of trucks was increased.

Table 1. Experimental design

Run	Description
Baseline Run1	50 truck locations
Run2	20 truck locations
Run3	10 truck locations
Run4	8 truck locations
Run5	7 truck locations
Run6	5 truck locations
Run7	Run3 with addition trains arriving every five days
Run8	Run3 with addition trains arriving every three days

The ProcessModel was run for twenty hours to reach steady state and another 160 hours after reaching steady state. The 160 hours is assumed to be one month of terminal operations.

MODEL INPUT

The data input for the Baseline Run1 was:

- Time between arrivals
 - Ships (1440 minutes, or four days)
 - Trucks with full containers (5 minutes)
 - Trucks with no containers (4 minutes)
 - Trucks with empty containers (120 minutes)

- Trucks arriving with full container
 - 98% exit with no container
 - 1% exit with empty container
 - 1% exit with full container
- Trucks arriving with no container
 - 100% exit with full container
- Trucks arriving empty
 - 99% exit with full container
 - 1% exit with no container
- Incoming containers on ships $T(350,400,450)$ ($T = t$ distribution with parameters a, b, c)
- Outgoing containers on ships $T(250,300,350)$
- $T(15,20,25)$ minutes for tug to position ship
- $T(9,10,11)$ minutes for inspector to inspect ship
- 2 minutes for crane to unload one container from ship
- 2 minutes to process paperwork before loading ship or truck
- 2 minutes for crane to load one container on ship
- $T(4,5,6)$ minutes for tug to move ship into channel for exiting
- $T(15,20,25)$ minutes for ship to leave port
- $T(2,3,4)$ minutes to position incoming trucks with full container, truck empty, or truck with empty container
- $T(2,3,4)$ minutes to inspect container on incoming truck
- $T(4,5,6)$ minutes for truck with container, empty truck, or truck with empty container to leave terminal
- 2 minutes for stacker to load empty container or full container on truck
- 2 minutes for stacker to unload container from cart at container yard
- 2 minutes for stacker to load container on cart at container yard
- 2 minutes to move cart from ship dock to container yard
- 2 minutes to move cart from container yard to ship dock
- $T(4,5,6)$ minutes to position truck with no container or truck with empty container
- $T(4,5,6)$ minutes to move cart from container yard to ship
- $T(4,5,6)$ minutes to move cart from ship to container yard

All incoming containers from ship exit on trucks. All incoming containers from trucks exit on ships. There is one container per truck.

75% of incoming containers from trucks are inspected. 15% of containers from ships are certified safe containers and are moved on a chassis directly to container yard. The time to move these containers to the container yard is $T(4,5,6)$ minutes. The remaining 85% of containers from ships are moved on a chassis to an inspection area. Of these containers 98% are given a tailgate inspection. The time for the tailgate inspection is $T(6,8,10)$ minutes. Containers are then moved on a chassis to the container yard in $T(2,3,4)$ minutes.

The remaining two percent of the inspected containers are given an extensive inspection. The inspection time is $T(240,300,360)$ minutes. Containers are then moved on a chassis to the container yard in $T(2,3,4)$ minutes.

A simplified and rapid approach to data collection is to ask the appropriate questions through interviews with personnel directly involved with the application (the expert). This is not only effective, but also a very time saving approach to obtaining data. In these instances the triangular distribution is often used as a subjective description of a population when there are only limited sample data and especially where actual data are scarce and the cost of collection high.

For example, if the smallest value, the largest value and the most likely value are known for a process, then the outcome can be approximated by the triangular distribution. Most personnel engaged in a process can readily give estimates for the minimum, maximum and most likely values which correspond to the three parameters of the triangular distribution

The Baseline Run1 had the following resources:

- 2 ship berths
- 2 ship cranes (loading and unloading containers on and off ship)
- 2 tugs
- 50 truck locations (maximum allowed number of trucks in terminal at a time)
- 20 chassis (moving containers between ship and container yard)
- 10 stackers (loading and unloading containers at container yard)
- 3 inspectors (inspecting incoming ships and trucks with full containers)

The Baseline Run1 had the following resource capacities:

- Maximum of 10 chassis at a time can move chassis with containers from dock to container yard
- Maximum of 10 chassis at a time can move with containers from container yard to dock

The Baseline Run1 had the following entity movement constraints:

- Full containers are moved on a chassis from ship dock to container yard as soon as unloaded from ship. Maximum of ten empty chassis can be positioned at the ship dock.
- Full containers are moved on chassis from the container yard to the ship dock only when the ship is unloaded and ready to begin loading. Maximum of ten full chassis for loading are allowed at the ship dock.

BASELINE RUN RESULTS

The ProcessModel for the Baseline Run1 was run for twenty hours to reach steady state and another 160 hours after reaching steady state. Table 2 gives the results for the Baseline Run1.

The average time a ship was in the terminal was 1,851 minutes. The average time an incoming truck with a container was in the terminal was 12 minutes. The average time a truck arriving empty was in the terminal was 14 minutes.

Table 2. Simulation results for Baseline Run1

	Baseline Run1
Truck locations	50
Avg. Entities through Terminal	
Ships	7
Trucks Arriving with Full Container	1,920
Trucks Arriving Empty	2,400
Trucks Arriving with Empty Containers	80
Avg. time in terminal (min)	
Ships	1,851
Trucks Arriving with Full Container	12
Trucks Arriving Empty	14
Trucks Arriving with Empty Containers	12
Utilization	
Truck Locations (50)	12%
Stackers (10)	23%
Chassis (20)	43%
Ship Berths (2)	63%
Tugs (2)	1%
Ship Cranes (2)	62%
Inspectors (3)	15%
Containers	
In on Ship	3,043
In on Truck	2,160
Out on Ship	2,135
Out on Truck	2,722
Inventory	
Out on Ship	1
Out on Truck	288

The utilization of many of the resources is relatively low. Therefore, it may be possible to further reduce the number of these resources without any impact on terminal operations. For example, based on current ship traffic one tug may be sufficient since tug

utilization was only 1%. Also, the stackers had a utilization of 23% and the chassis had a utilization of 43%. These resources probably could be reduced at the modeled volumes.

Table 3 displays a comparison of the mean time an entity was in the terminal with the value added time for the Baseline Run1. The difference between the two times is the delay time the entity had to wait for a resource, activity or a container. The only entity delay was ships. A ship had to wait an average of 402 minutes while trucks had no delay times. Several reasons for this delay may be the lack of containers at the dock for loading and the availability of a cart to move the container from the container yard to the dock.

Table 3. Comparison of mean times with value added times for Baseline Run1

Entity	Number of entities	Mean time in terminal (min)	Mean value added time in terminal (min)	Delay time (min)
Ships	7	1,851	1,449	402
Trucks Arriving with Full Container	1,920	12	12	0
Trucks Arriving Empty	2,400	14	14	0
Trucks Arriving with Empty Container	80	12	12	0

DECOUPLING CONTAINER INSPECTIONS

A previous study by Harris, et.al. (2009) evaluated three inspection protocols: A) no inspection, B) container sampling with unloading and inspection coupled and C) inspection after unloading or decoupling inspection from unloading. Any sampling plan using Protocol B had an impact on entity throughput. Decoupling the inspection from unloading in Protocol C did not impact entity throughput. In fact, entity throughput for Protocol C was similar to no container inspection for Protocol A. As a result of this study the ProcessModel in this paper decoupled the inspection.

CONSTRAINING TRUCK TRAFFIC INSIDE TERMINAL

Table 4 shows the results of continuing decreasing the number of truck locations in the terminal (Runs2-6). The Baseline Run1 has fifty truck locations which defines the maximum number of trucks that are permitted in the terminal at one time. Runs2-6 slowly decreased the maximum number of locations until delays occurred in the processing of terminal entities.

Figure 4 is a plot of truck slot utilization as a function of number of truck locations. Truck slot utilization was 12% with fifty truck locations. Slot utilization increased to 30% with 20 truck locations, 60% with 10 truck locations, 76% with eight truck locations, 86% with seven locations and 100% with five truck locations.

Entity times through the terminal remained constant until seven or fewer truck locations (Runs5-6). The time a truck was in the terminal was 12 minutes with no delays with seven truck locations and increased to 549 minutes with five truck locations. Therefore,

it appears that a minimum of ten truck locations is adequate to handle the defined entity arrival rates.

Table 4. Simulation results for Runs2-6

	Baseline Run1	Run2	Run3	Run4	Run5	Run6
Truck locations	50	20	10	8	7	5
Avg. Entities through Terminal						
Ships	7	7	7	7	7	6
Trucks Arriving with Full Container	1,920	1,920	1,920	1,921	1,920	1,799
Trucks Arriving Empty	2,400	2,400	2,400	2,400	2,400	1,786
Trucks Arriving with Empty Containers	80	80	80	80	80	80
Avg. time in Terminal (min)						
Ships	1,851	1,851	1,836	1,906	1,847	2,109
Trucks Arriving with Full Container	12	12	12	12	12	549
Trucks Arriving Empty	14	14	14	14	14	1,464
Trucks Arriving with Empty Containers	12	12	12	12	11	275
Utilization						
Truck Locations	12%	30%	60%	76%	86%	100%
Stackers	23%	23%	23%	23%	23%	21%
Chassis	43%	44%	41%	42%	42%	40%
Ship Berths	63%	63%	63%	66%	62%	73%
Tugs	1%	1%	1%	1%	1%	1%
Ship Cranes	62%	62%	62%	64%	62%	72%
Inspectors	15%	15%	15%	15%	15%	14%
Containers						
In on Ship	3,037	3,037	3,029	3,113	2,965	3,073
In on Truck	2,159	2,159	2,160	2,159	2,159	1,990
Out on Ship	2,072	2,072	2,030	2,117	2,088	1,976
Out on Truck	2,723	2,723	2,715	2,723	2,725	2,045
Inventory						
Out on Ship	83	69	103	23	50	0
Out on Truck	288	262	261	348	207	994

The results of the Baseline Run1 indicated monthly container traffic of 5,203 containers in from ship and truck and 4,857 containers out on ship and truck. This equate to annual container traffic of:

Containers in	62,436
Containers out	58,284
<u>Containers in container yard</u>	<u>3,468</u>
Total containers handled	124,188

The first year of operations of the container terminal was 130,000 TEUs. The simulation results closely approximated the actual container activity.

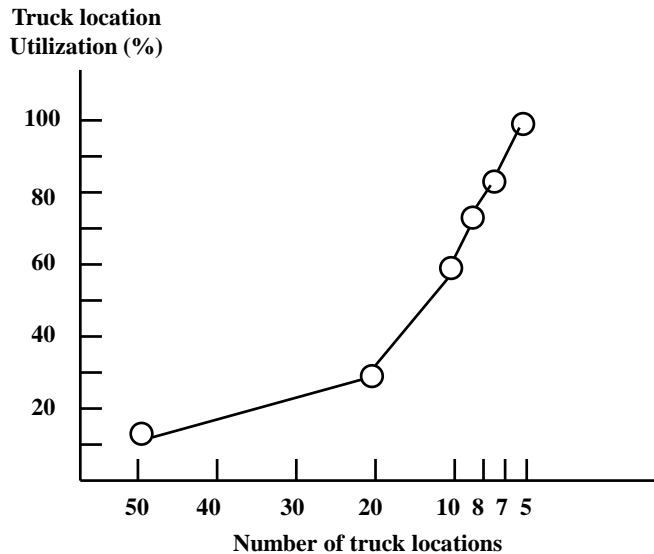


Figure 4. Truck slot utilization versus number of truck locations

Based on the simulation results from Run1 an estimated 2,400 trucks with no containers, 80 trucks with empty containers and 1,920 trucks with full containers will arrive at the terminal monthly. This equates to a total of 4,400 trucks entering and leaving the terminal monthly or 220 trucks a day. These trucks will generally leave the terminal on interstate I65 north or I10 going east or west.

OFFLOADING TRUCKS ONTO RAIL

One approach to reducing the volume of truck traffic is to have containers enter and leave the terminal on rail. The ProcessModel was modified to include trains. The additional input data were:

- Incoming containers on trains T(90,100,110)
- Outgoing containers on ships T(90,100,130)
- T(15,20,25) minutes to position train
- T(9,10,11) minutes to inspect train
- 2 minutes for train crane to unload one container from train
- 2 minutes to process paperwork before loading train

- 2 minutes for crane to load one container on train
- T(4,5,6) minutes for train to leave terminal

Table 5 gives the time between arrivals for trucks and trains for Runs7-8. The truck arrivals were lowered and the train traffic was included for Runs7-8. A train arrived and departed the terminal with an average of 100 containers. Ship traffic remained constant.

Table 5. Time between arrivals for trucks and trains

Entity	Run3	Run7	Run8
Trucks Arriving with Full Container	5 minutes	6 minutes	7 minutes
Trucks Empty	4 minutes	5 minutes	6 minutes
Trains	2,440 minutes (or five days)	2,440 minutes (or five days)	1,440 minutes (or three days)

The following three additional submodels were added to ProcessModel:

- Train unloading and loading of containers
- Movement of containers from train pavement to container yard
- Movement of containers from container yard to train pavement

These submodels required two new resources: train locations and train cranes. Also the submodels added four entity attributes, two global variables, twenty-seven activity blocks and three entity blocks.

Table 6 presents the simulation results for Runs7-8 compared with Run3 after running the model for one month or twenty days. All three runs had only ten truck locations.

Figure 5 is a plot of the number of containers leaving the terminal by ship, truck and train. Figure 6 is a plot of the entity traffic. The results in both figures are compared with Run3 since Run3 is identical to the Baseline Run1 with the exception of only having ten truck locations.

The times to process ships and truck remained relatively constant. However, as anticipated truck traffic decreased from 4,400 for Run3 to 3,600 for Run7 and to 3,051 for Run8. At the same time train traffic through the terminal was 5 trains for Run7 and 7 trains for Run8.

Table 6. Simulation results for Baseline Run1 (one month simulation)

	Run3	Run7	Run8
Truck locations	10	10	10
Avg. Entities through Terminal			
Ships	7	7	7
Trucks Arriving with Full Containers	1,920	1,600	1,371
Trucks Arriving Empty	2,400	1,920	1,600
Trucks Arriving with Empty Containers	80	80	80
Trains	na	5	8
Avg. time in terminal (min)			
Ships	1,866	1,919	1,874
Trucks Arriving with Full Containers	12	12	12
Trucks Arriving Empty	13	14	14
Trucks Arriving with Empty Containers	12	12	12
Trains	na	768	753
Utilization			
Truck Locations	60%	49%	41%
Stackers	22%	23%	24%
Chassis	40%	51%	56%
Ship Berths	63%	66%	64%
Tugs	1%	1%	1%
Ship Cranes	62%	65%	63%
Train Cranes	na	12%	23%
Inspectors	15%	13%	11%
Containers			
In on Ship	2,958	3,121	3,090
In on Truck	2,159	1,799	1,542
In on Train	na	508	805
Out on Ship	2,090	2,181	2,069
Out on Truck	2,715	2,159	1,799
Out on Train	na	520	858
Inventory			
Out on Ship	42	126	278
Out on Truck	204	185	361
Out on Train	na	247	66

For Run7 a total of 520 containers exited the terminal on five trains that is equivalent to removing 520 trucks exiting the terminal with containers. The input data for the time between arrivals for empty trucks was increased from four to five minutes. Therefore, rather than 2,400 empty truck arrivals during month for the Baseline Run1, there were only 1,920 arrival for Run7, or a reduction of 480 trucks.

Likewise, the input data for the time between arrivals for trucks with containers was increased from five minutes for the Baseline Run1 to six minutes for Run7. Therefore, rather than 1,920 truck arrivals, there were only 1,600 arrivals, or a reduction of 300 trucks. A total of 480+300 or 780 trucks were removed from the traffic in the Mobile area.

As anticipated, for every container arriving on train a truck is removed from delivering a container to the terminal. Also for every container leaving the terminal on train a truck is removed.

The interstate truck traffic was lowered by 18% in Run7 with the arrival of a train every five days. The interstate truck traffic was lowered by 31% in Run8 with the arrival of a train every three days.

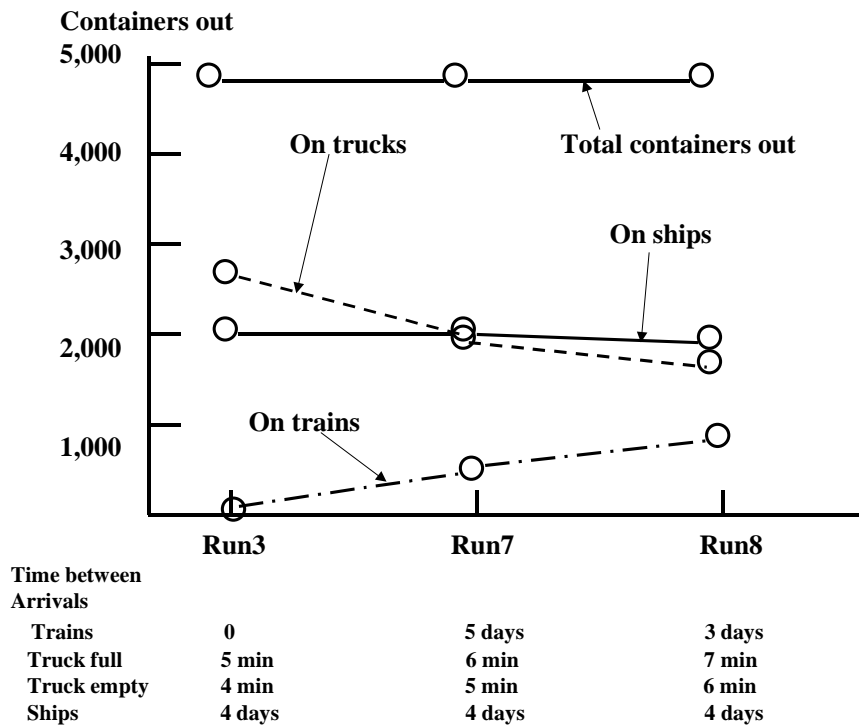


Figure 5. Monthly containers leaving terminal

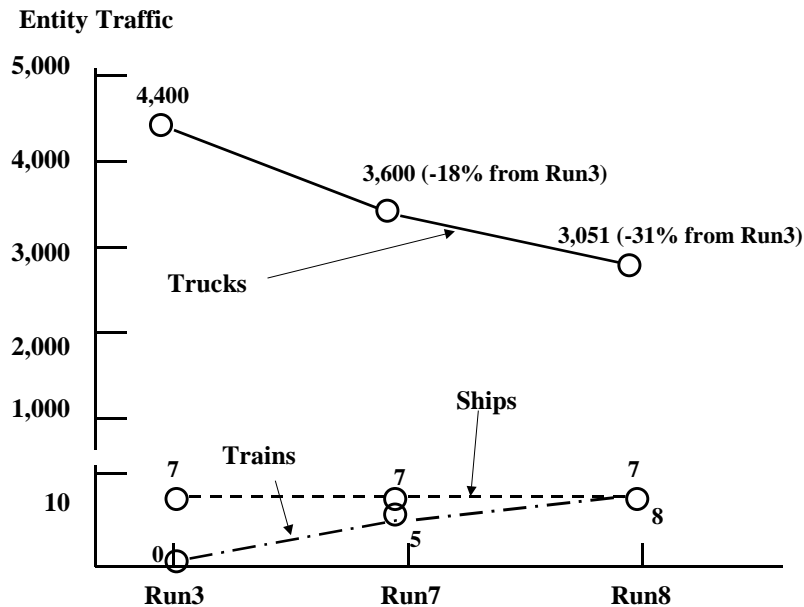


Figure 6. Monthly entity traffic

CONCLUSIONS

In summary the following conclusions are made:

- Trucks locations are used in the ProcessModel to control the maximum number of trucks in the container terminal. As a result, the number of truck locations is an important measure of the amount of space needed within the terminal for truck traffic. The Baseline Run1 had fifty truck locations, or resources. Runs2-6 continually reduced the number of truck locations. It appears that given the existing entity arrival rates only ten truck locations are necessary. The result with ten truck locations was identical to the results with fifty truck locations. The number of locations will probably have to increase if there is an increase in container volume.
- The truck entities for the Baseline Run1 and many of the other runs experienced no delays (that is, the total time in the terminal equaled the value added time). However, the ships and trains experienced delays. For the Baseline Run1 the average ship delay was 402 minutes. For Run7 the average ship delay was 414 minutes and the average train delay was 321 minutes. These delays were probably due to the lack of containers or the availability of a resource.
- The container terminal will have a significant impact of truck traffic in and out of Mobile. A ship arriving every four days (or about seven ships a month) with an average of 450 containers for import and 350 containers for export will require 350 trucks to bring in containers for export and another 450 trucks to move the

incoming containers from ship inland. This traffic volume will occur every four days, which is the time between arrivals of ships.

- Run3 estimated 4,400 trucks a month (or 220 per day) will be added to the interstate traffic in Mobile with the arrival of a container ship every four days.
- The addition of train service to the container terminal will reduce the truck traffic servicing the terminal. Run7 included a train arriving every five days with 100 containers. Also the input data for the time between arrivals of trucks with containers was increased from 5 minutes for Run3 to 6 minutes for Run7. The input data for the empty truck arrivals were increased from 4 minutes for Run3 to 5 minutes for Run7. The simulation indicated at 18% reduction in truck traffic with a train arriving every five days.
- The arrival of a train every three days in Run8 had a 31% reduction in truck traffic. The input data for the arrival of trucks with containers was increased to 6 minutes and the empty truck arrivals were increased to 7 minutes.
- The 18% reduction in truck traffic for Run7 is about 900 trucks per month or about 45 trucks a day. The 31% reduction in truck traffic for Run8 is about 1,350 trucks per month or about 67 trucks a day.
- For every container that arrives on a train a truck is removed from delivering a container to the terminal. Also for every container that arrives on a ship and leaves the terminal on train a truck is removed from the Mobile road network.
- Many of the resources had relative low utilizations. Therefore, it may be possible to further reduce these resources without impacting the terminal operations.

ACKNOWLEDGEMENTS

This research was sponsored by the U.S. Department of Transportation, Federal Transit Administration, Project No. AL-26-7262-01.

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