CONTAINER SECURITY INSPECTION: SIMULATION TO EVALUATE VARIOUS CONTAINER SAMPLING PLANS ON PORT OPERATIONS

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ABSTRACT
This paper presents a simulation model to determine the impact of various container inspection sampling plans on the operation of a seaport container terminal. Of special interest is the turn around times for ships, trains and trucks. Included in this paper are the development of the simulation model, the experiment to evaluate the impact of increased security on port operations, an analysis of the simulation results and conclusions.

KEYWORDS
Security, container, terminal, seaport, simulation

1. INTRODUCTION

Over ninety percent of cargo currently transported worldwide is being shipped as containerized cargo. At the same time increased security is having a significant impact on the operation of seaports. Increased inspections result in more time unloading and loading containers off and on ships, train and trucks. The resulting effect is longer times for ships, trains and trucks at the container terminals.

Simulation offers an excellent approach to evaluate the impact of container inspections on terminal operations. This paper presents a simulation model to determine the impact of various container inspection sampling plans on the operation of a container terminal at a seaport. Of special interest is the turn around times for ships, trains and trucks. The container terminal is located at the Alabama State Docks in Mobile, Alabama.

2. CONTAINER TERMINAL

Figure 1 is a sketch of the simulated container movement at the terminal located at the Alabama State Docks. Containers arrive and depart on ships, trains and trucks. The initial inspection plan modeled was to inspect incoming containers before entering the terminal. A team of inspectors is assigned to the port with the sole responsibility of inspecting incoming containers. Ship cranes and train cranes unload and load containers. Stackers load and unload containers on and off trucks and carts. Carts move the containers throughput the terminal such as moving carts from the ship dock to the container yard.

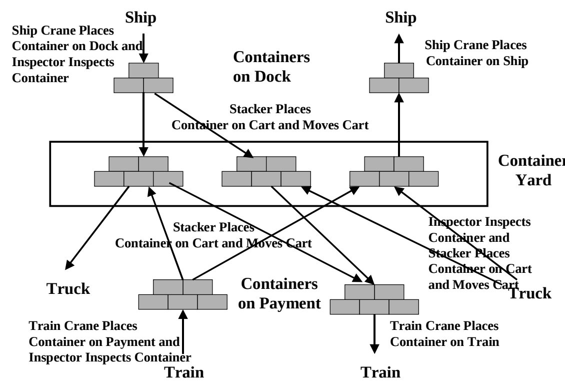

Figure 1. Overview of container traffic

3. SIMULATION MODEL

The ProcessModel (1999) used in this study was initially written by Schroer et al. (2008b) to determine the inspector staffing requirements for the container terminal at the Alabama State Docks. This initial model was constructed following the conceptual framework developed by Schroer, et.al. (2008a). This conceptual framework consists of a number of submodels that run independently. Each model 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
- Train 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
- Movement of containers from train pavement to container yard
- Movement of containers from container yard to train pavement

The terminal has the following resources: ship berths, ship cranes, train slots, train cranes, truck slots, stackers and carts. The model has thirteen entity attributes, twenty global variables, sixty-nine activity blocks and ten entity blocks.

4. EXPERIMENTAL DESIGN

Table 1 provides the experimental design to address the impact of increased security on seaport operations. The Baseline Run1 had no container inspectors. This Baseline run provided the researchers with a look at the flow of container unimpeded by constraints. An earlier study by Schroer et al. (2008b) concluded that five inspectors to perform inspections were adequate given the current entity arrival rates. Therefore, Run10 in this previous study was used as the basis for Run2. Runs3 through 6 are similar to Run2 with the exception of reduced container inspection rates.

Table 1. Experimental design

Run	Description
Run1	Baseline run with no container inspection
Run2	100% inspection of incoming containers
Run3	90% inspection of incoming containers
Run4	80% inspection of incoming containers
Run5	70% inspection of incoming containers
Run6	60% inspection of incoming containers

5. BASELINE RUN1

The input data for the Baseline Run1 are given in Tables 2 through 4. The baseline input data consisted of:

- Two ship berths for unloading and loading containers
- Two train slots for unloading and loading containers
- Twenty truck slots (Maximum number of trucks in terminal at one time)
- Two ship cranes for unloading and loading containers from planes
- Two train cranes for unloading and loading containers from trains
- Twelve stackers for unloading and loading containers from trucks and onto and off carts
- Twenty carts for moving containers throughout the terminal
- 2 minutes to unload or load a container from plane, train, or truck
- T(15,20,25) minutes to position a ship at a terminal (T = Triangular distribution)
- T(15,20,25) minutes to position a train at a terminal
- T(4,5,6) minutes to position a truck for unloading or loading
- 2 minutes to process paperwork to load a plane, train or truck
- T(4,5,6) minutes for plane, train, or truck to exit terminal
- 2 minutes to unload and load a cart
- T(4,5,6) minutes to move a cart between a plane, train or truck and the container yard

Table 2. Movement of containers

	Containers out		
Containers in	**Ship**	**Truck**	**Train**
Ship		10%	90%
Truck	70%		30%
Train	80%	2%	18%

Table 3. Entity parameters

Entity	Time between Arrivals (min)
Ship	T(1320,1440,1560)
Train	T(420,480,540)
Empty Train	T(2080,2320,2560)
Truck with Full Container	T(54,60,66)
Empty Truck	T(90,120,150)
Truck with Empty Container	T(180,240,300)
	Containers In
Ship	T(400,450,500)
Train	T(90,100,110)
Empty Train	0
Truck with Full Container	1
Empty Truck	0
Truck with Empty Container	1
	Containers Out
Ship	T(200,250,300)
Train	T(90,100,130)
Empty Train	T(90,100,150)

Table 4. Containers out on truck

Entity	Truck Leaves with no Container	Truck Leaves with Container	Truck Leaves with Full Container
Truck with Full Container	10%	9%	81%
Empty Truck			100%
Truck with Empty Container	100%		

The simulation model was run for 1,440 hours, or 180 eight-hour days, which equates to six months. The results of the simulation for the Baseline Run1 are shown in Table 5.

Table 5. Baseline Run1 results

Entities through Terminal	Qty.	Time (min)	Value Added Time (min)
Ships	59	2,013	1,349
Trains	180	684	441
Empty Trains	38	424	251
Trucks	1,440	26	14
Empty Trucks	725	21	11
Truck with Empty Container	358	27	14
Resource Utilization	**Qty.**	**Percent**	
Ship Berths	2	68	
Ship Cranes	2	67	
Tugs	2	1	
Train Slots	2	71	
Train Cranes	2	72	
Truck Slots	20	3	
Stackers	12	34	
Carts	20	52	
Containers	**Unloaded**	**Loaded**	**Still at Terminal**
Ships	23,746	15,309	224
Trains	18,185	23,407	564
Trucks	1,440	2,163	1,696
Empty Containers	358	156	202
Total	43,729	41,035	2,686

Several observations for the Baseline Run1 are:

- Relative high utilization for ship berths and cranes of 68% and 67% respectively.
- Relative high utilization for train slots and train cranes of 71% and 72% respectively.
- Very low utilization of tugs of 1% indicating one less tug may be possible.
- Very low utilization of twenty truck slots (maximum number of allowed trucks in the terminal at one time). It may be possible to reduce this resource and thus freeing up space for other terminal operations.
- Fewer stackers are possible since average utilization is 34%.

6. 100% CONTAINER INSPECTION RUN2

The additional inspection times for Runs2 through 6 are:

- T(10,15,20) minutes for inspector to check paperwork before unloading of containers from ship or train (T = triangular distribution)
- T(2,3,4) minutes for inspector to check paperwork and container from truck
- 3 minutes for inspector to inspect a container from a ship, train or truck
- Five inspectors available to inspect containers

Table 6 presents the results of Run2. The simulation model was run for 1,440 hours, or 180 eight-hour days. Ship berths and cranes were almost 100% utilized. Likewise, train slots and cranes were almost 100% utilized. These near 100% utilizations indicate long waits for both ships and trains during unloading and loading. Waiting time is calculated by subtracting the value added time from the total time the entities were in the model.

Ship waiting time was 4,703 minutes and train waiting was 3,200 minutes. These increases in delays are the result of the container inspection times.

The five inspectors were utilized an average of 56%. Because of the rather large time between arrivals for ships all the inspectors are probably fully busy when ships and trains are in the terminal, and idle between arrivals.

Ships through the terminal dropped from 59 with no container inspection (Run1) to 53 (-10%) with 100% inspection (Run2). Likewise, the time for a ship at the terminal increased significantly from 2,013 minutes with no container inspection to 7,258 minutes (+260%) with 100% inspection. Trains through the terminal dropped from 180 with no container inspection to 166 (-7%) with 100% inspection. The time for a train at the terminal increased from 684 minutes with no container inspection to 3,952 (+477%) with 100% inspection. The truck throughput remained constant (1,440 to 1,441); however, the time for a truck at the terminal increased from 26 minutes with no container inspection to 51 minutes (+96%) with 100% inspection. The containers through the terminal were 43,729 with no container inspection (Run1) but reduced to 40,224 (-8%) with 100% inspection.

Table 6. Run2 results 100% inspection

Entities through Terminal	Qty.	Time (min)	Value Added Time (min)
Ships	53	7,258	2,555
Trains	166	3,952	752
Empty Trains	37	593	253
Trucks	1,441	51	20
Empty Trucks	724	42	12
Truck with Empty Container	358	45	14
Resource Utilization	**Qty.**	**Percent**	
Ship Berths	2	99%	
Ship Cranes	2	98%	
Tugs	2	1%	
Train Slots	2	99%	
Train Cranes	2	96%	
Truck Slots	20	6%	
Stackers	12	32%	
Carts	20	48%	
Inspectors	5	56%	
Containers	**Unloaded**	**Loaded**	**At Terminal**
Ships	21,707	13,454	924
Trains	16,718	21,842	1,184
Trucks	1,441	2,176	279
Empty Containers	358	126	232
Total	40,224	37,598	2,619

7. VARYING PERCENTAGE OF CONTAINERS INSPECTED RUNS3 THROUGH 6

Tables 7 and 8 present the results for Runs3 through 6 with sampling plans of varying percentages of container inspections. The simulation models were run for 1,440 hours, or 180 eight-hour days.

As anticipated, entity throughput increased and entity time at the terminal decreased with each reduction in the percentage of container inspections.

Ships through the terminal increased from 53 with 100% inspection (Run2) to 59 (+10%) with 60% inspection (Run6). Note that the ships through the terminal were 59 with no inspection (Run1). The time for a ship at the terminal decreased from 7,258 minutes for 100% inspection to 2,778 minutes (-61%) with 60% inspection. Also note that the ship time was 2,013 minutes with no inspection.

Table 7. Entity times for Runs3&4

Entity	Run3		Run4	
Sampling	**90%**		**80%**	
	Qty.	**Time (min)**	**Qty.**	**Time (min)**
Ships	55	5,369	57	3,677
Trains	170	3,646	176	1,966
Empty Trains	37	547	37	532
Trucks	1,441	38	1,439	34
Empty Trucks	721	28	720	23
Trucks/W Empty Containers	358	34	361	28
Inspectors	5		5	
Inspection	90%		80%	
Utilization	65%		54%	

Likewise, trains through the terminal increased from 166 with 100% inspection (Run2) to 179 (+7%) with 60% inspection (Run6). The ships through the terminal were 180 with no inspection (Run1). The time for a train at the terminal decreased from 3,952 minutes with 100% inspection to 987 minutes (-75%) with 60% inspection. The train time was 684 minutes with no inspection.

Table 8. Entity times for Runs5&6

Entity	Run5		Run6	
Sampling	70%		60%	
	Qty.	Time (min)	Qty.	Time (min)
Ships	58	3,005	59	2,778
Trains	178	1,033	179	987
Empty Trains	37	528	38	502
Trucks	1,440	36	1,439	32
Empty Trucks	720	25	717	21
Trucks/W Empty Containers	358	31	360	27
Inspectors	5		5	
Inspection Utilization	70% 52%		60% 49%	

8. CHANGE INSPECTION PROTOCOL RUN7

The various sampling procedures all produce sub-optimal results based on elapsed time in the port. The times ships, trains and trucks were in the terminal were still significantly greater even with a 60% container sampling plan.

Therefore, a new inspection protocol was evaluated. Initially the protocol for the Baseline Run1 consisted of no container inspection. The protocol for Runs2 through 6 consisted of unloading and inspecting containers simultaneously (cannot unload another container until prior container inspected).

A third protocol (Run7) consisted of inspecting containers independently of unloading them from the ship (continue unloading containers with inspection performed prior to moving to container yard). In effect the inspection is decoupled from the unloading of containers. The new ship logic is:

- Security inspector checks ship's paperwork
- Ship crane unloads container onto dock (continue unloading even though containers not inspected)
- Process repeated until all containers unloaded
- After container on dock security inspector inspects container
- Stacker places container on cart
- Cart moves container to container yard
- Process repeated until all containers are moved

Table 9 presents the results for Run7. The simulation model was run for 1,440 hours, or 180 eight-hour days. Surprisingly the results were identical to Run1 with no container inspection. Also surprising was that the security inspection did not delay the loading of containers onto ships, trains and trucks. The simulation model does not have the necessary detail logic to uniquely identify a container in the terminal and to assign the container for loading on a specific entity. As a result, as long as containers are in the container yard the loading continues.

Table 9. Results for Run7

Entities through Terminal	Qty.	Time (min)	Value Added Time (min)
Ships	59	2,007	1,352
Trains	180	695	450
Empty Trains	38	430	255
Trucks	1,442	33	20
Empty Trucks	719	21	12
Truck with Empty Container	360	27	14
Resource	**Qty.**	**Utilization**	
Ship Berths	2	67%	
Ship Cranes	2	67%	
Tugs	2	1%	
Train Slots	2	72%	
Train Cranes	2	72%	
Truck Slots	20	4%	
Stackers	12	34%	
Carts	20	52%	
Inspectors	5		
Containers	**Unloaded**	**Loaded**	**At Terminal**
Ships	23,669	14,786	674
Trains	18,105	23,506	1,512
Trucks	1,443	2,137	592
Empty Containers	360	167	193
Total	43,577	40,596	2,971

9. ANALYSIS

Figures 2 through 4 are plots of the ship, train and truck times at the terminal, respectively. As anticipated, the times through the terminal increased with an increase in the percentage of containers inspected (for Runs 2 through 6).

However, it appears that the large increases in time through the terminal for ships and trains occurred when container inspections were greater than 70%. Note that the entity times for Run7 with the new inspection plan (with 100% container inspection) was almost identical to the Baseline Run1 with no inspection. The only increase was the truck time to 33 minutes for Run7 from 26 minutes for the Baseline Run1.

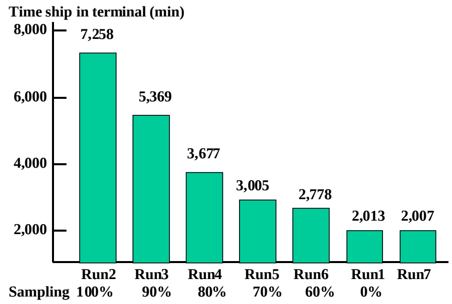

Figure 2. Ship time at terminal

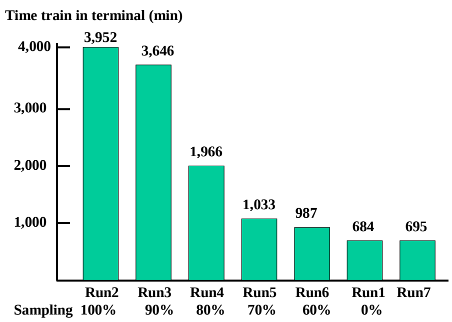

Figure 3. Train time at terminal

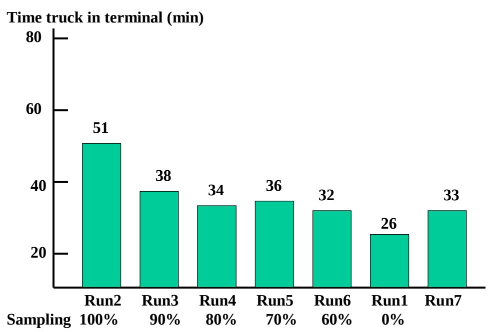

Figure 4. Truck time at terminal

Figure 5 presents a plot of the total full containers unloaded at the terminal. The total in for the Baseline Run1 was 43,371 containers, 39,866 (-8%) for 100% inspection and 43,692 (-0%) for Run5. The total containers for Run7 with 100% inspection were almost identical to the Baseline Run1 with no inspection.

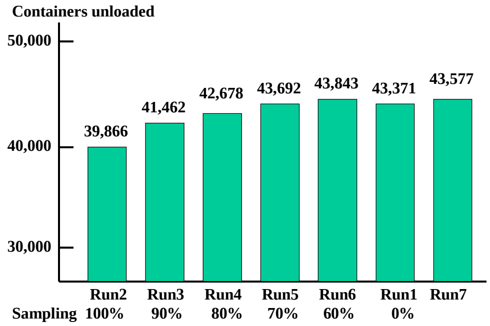

Figure 5. Full containers unloaded

10. CONCLUSIONS

This simplified look at the effect of inspection protocol on the velocity of freight through the a port was effective in helping stakeholders understand the cause and effect relationships between inspection activities and the flow of freight through a port. A focus on equipment utilization only may actually be detrimental to the flow and velocity of freight.

In summary the following conclusions are made:

- Container inspections significantly impacted terminal operations using the sampling plan for Runs2 through 6. However, lowering the sampling rate greatly reduces this impact. For example, a 70% inspection rate reduced the impact on ship throughput from 7,258 minutes for 100% inspections to 3,005 minutes for 70% (-58%) inspection.

- The ship wait time for 100% inspection (Run2) was 4,703 minutes and 1,656 minutes for 70% inspection (Run5). These long wait times are the result of very high utilizations of ship berths and train slots. As a result the terminal may be at capacity without additional ship berths and train slots (this is the result of the sampling protocol of inspecting a container before unloading another container).

- A relative large number of container inspectors are necessary even for a terminal with small container throughput. Five inspectors were required even when the inspection rates were reduced (this is the result of the selected sampling protocol).

- The inspection protocol for Run7 consisted of decoupling the inspection from the unloading of containers. This new sampling protocol resulted in almost identical entity times at the terminal as the Baseline Run1 with no inspection. With the new protocol in Run7 containers were unloaded directly onto the dock without inspection. The inspection occurred when the container was placed on a cart for transport to the container yard. As a result the unloading process was never delayed because of the inspection.

- Modifying the previously developed simulation model to include container inspection was rather easy. Only one block had to be added in the ship, train and truck submodels to include the sampling rate and the inspection times. However, the adding of the inspection logic for Run7 required the moving of logic between several of the ProcessModel blocks.

Container inspection protocols are critical in minimizing delays at the terminal. It is obvious that any sampling protocol must be decoupled as much as possible from the actual unloading of containers. If not any container inspection will ripple through the system and result in longer times for ships, trains and trucks in the terminal.

The protocol for Run7 is probably not realistic. After discussion with dock's personnel it appears that the actual container inspection is a variation the Run7. However, using simulation, it is a rather simple modification to the ProcessModel to evaluate the impact of these sampling protocols on overall terminal operations.

11. ACKNOWLEDGEMENTS

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