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Resources to Minimize Disruption Caused by Increased Security Inspection of Containers at an Intermodal Terminal

Application of Simulation

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This paper presents the application of simulation to determine the inspection resources needed to minimize disruption resulting from increased security inspection of containers at an intermodal terminal. The initial simulation run intentionally started with a large number of resources. Additional simulation runs were made with a continual reduction of inspection resources until entity throughput at the terminal dropped below allowable limits. Simulation Run 9, with six tailgate inspection stations, three intensive inspection stations, and one general purpose inspector, provided the minimum resources that did not disrupt container throughput. This paper includes the description of the conceptual model framework, the simulation model, the experimental design, and simulation results.

The container terminal at the Alabama state docks is currently undergoing a major expansion (*1*). The terminal is an intermodal facility with containers arriving and departing via ships, trains, and trucks. As a result of this expansion and increased security issues worldwide, there is considerable interest in determining the impact of increased container inspection and the number of inspection resources necessary to minimize the disruption in terminal operations. This paper presents the use of simulation as a tool to determine the needed resources to minimize the disruptions to port terminal operations resulting from increased security inspection of containers.

RELATED RESEARCH

Advanced modeling and simulation and analysis of critical infrastructures, their interdependencies, and vulnerabilities are provided by the National Infrastructure Simulation and Analysis Center (NISAC) under the Department of Homeland Security. NISAC is a partnership between Sandia National Laboratories and Los Alamos National Laboratories. NISAC developed the port operations simulator to analyze the flow of shipping containers through a container terminal and examine the impact of additional security measures on the flow of goods such as increased inspections, scanners at various locations, and new security policies. The simulator also examines the effect of failure of port-related infrastructure such as electrical power and telecommunications (*2*). The simulator was originally tailored for the ports of Portland, Oregon, and Seattle, Washington, and is used in evaluating the potential consequences of security policies.

Lewis et al. developed a model for aiding the management of a container seaport in deciding on the balance between the percentage of containers to undergo security inspection and the concomitant departure delays of outbound vessels (*3*).

Bocca et al. developed a modeling and simulation and data fusion integration to provide an efficient tool to test and improve container inspection reliability by taking into consideration, at the same time, the impact of different security levels on system performance (*4*). Two models have been developed: a virtual cargo generator that provides different security scenarios and a seaport simulation model that monitors container inspection and the impact of different security levels on port performance. Bruzzone et al. developed a simulation and virtual reality model to support the design of safety procedures in harbors (*5*).

SIMULATION MODEL

The conceptual framework developed by Schroer et al. was used in constructing this simulation model (*6*), and it has been successfully used in similar modeling efforts at the port of Mobile (*7*). The framework consists of a number of submodels that run independently. Each model has its own data input and entities with specific attributes. Within the conceptual framework, data are shared between the submodels by global variables. The content of the global variables can be altered in any submodel with the new values immediately shared and used by any other submodel. These global variables not only pass data between the submodels but can also be used in logic statements to control the movement and routing of entities, logic for branching, and updating entity attributes.

ProcessModel was selected to develop the conceptual framework (*8*). The building blocks in ProcessModel are ideal for constructing the submodels. ProcessModel has four building blocks: activities,

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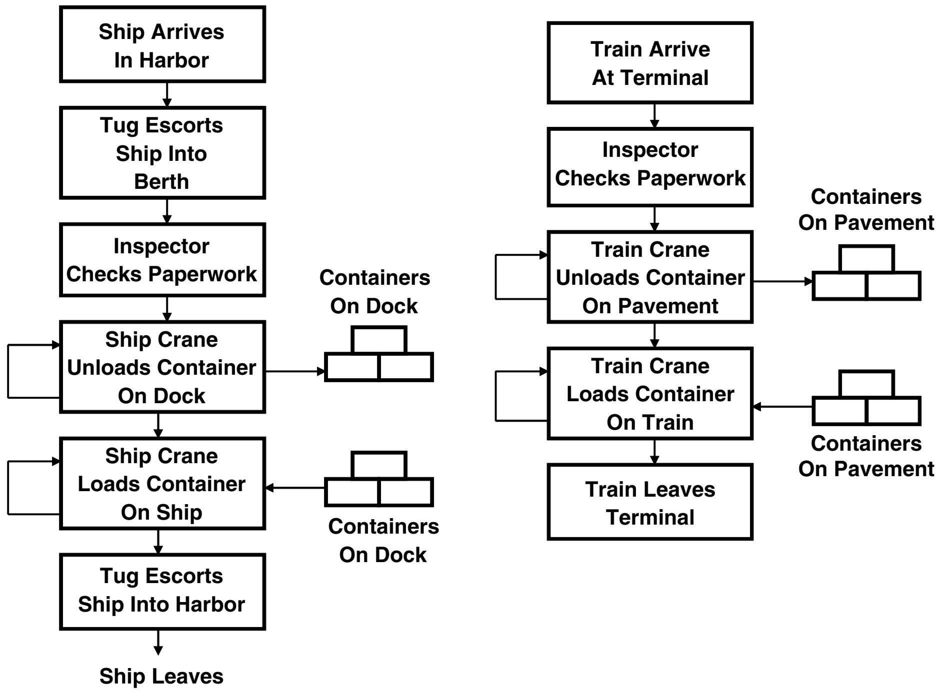

FIGURE 1 Simulation logic for unloading and loading ships (Submodel A) and trains (Submodel B).

entities, resources, and stores. Within each block, and for each routing option (connecting line), complex logic can be added. Global variables and entity attributes can be easily defined. ProcessModel has a label block feature that can be used to display the current content of selected global variables during the simulation. Translating the intermodal container terminal into the conceptual framework resulted in the following submodels:

Submodel A. Ships—unloading and loading of containers (entity = ship) (Figure 1);

Submodel B. Trains—unloading and loading of containers (entity = train) (Figure 1);

Submodel C. Trucks—unloading and loading of containers (entities = truck, empty truck, and empty truck with container) (Figure 2);

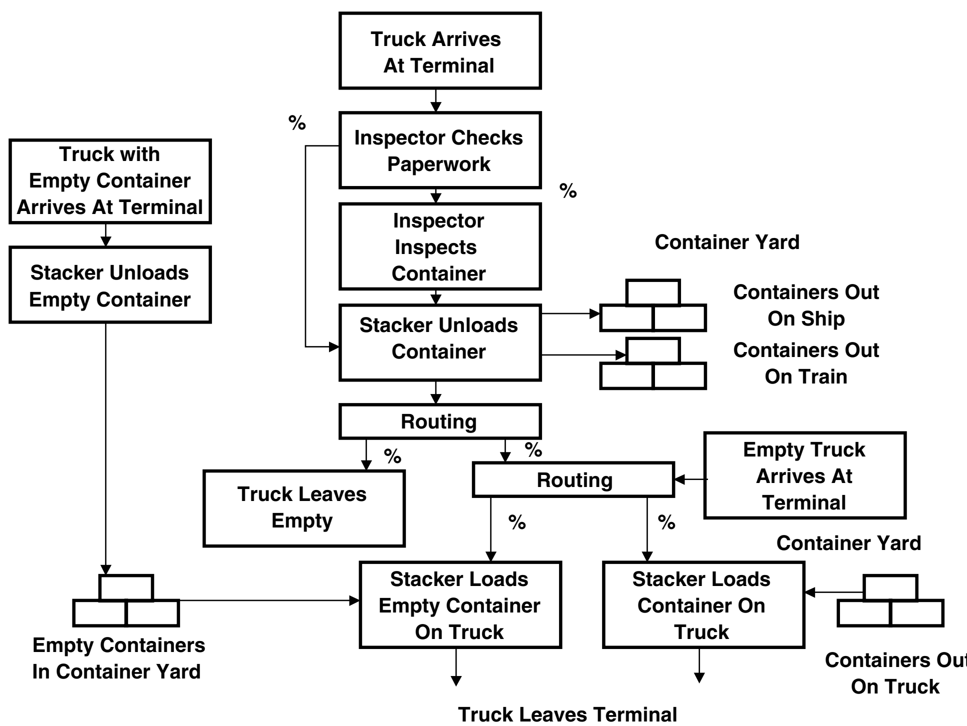

FIGURE 2 Simulation logic for unloading and loading trucks (Submodel C).

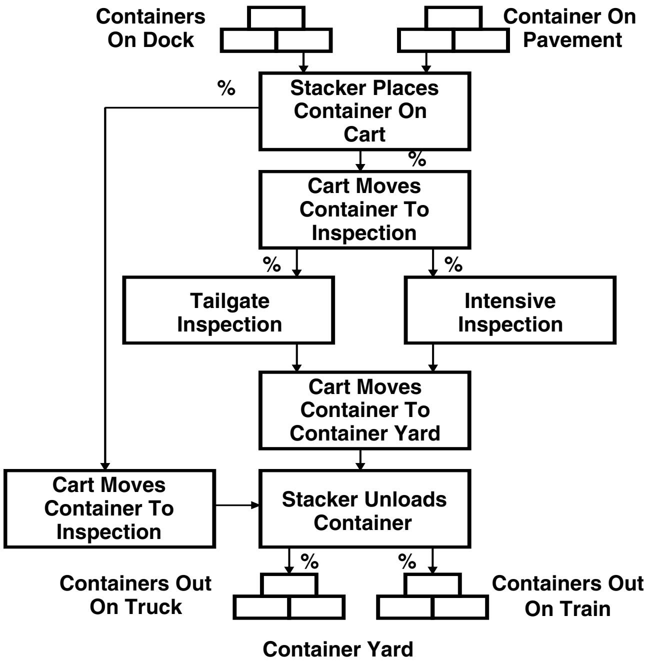

FIGURE 3 Simulation logic for moving containers from dock and pavement to container yard (Submodels D and F).

Submodel D. Movement of containers from ship dock to container yard (entity = move order1) (Figure 3);

Submodel E. Movement of containers from container yard to ship dock (entity = move order2) (Figure 4);

Submodel F. Movement of containers from train pavement to container yard (entity = move order3) (Figure 3); and

Submodel G. Movement of containers from container yard to train pavement (entity = move order4) (Figure 4).

The simulation model is a modification to a ProcessModel used to evaluate the container traffic at the Intermodal Center in Huntsville, Alabama (*9, 10*). Consequently, verification and validation had already been performed on the model.

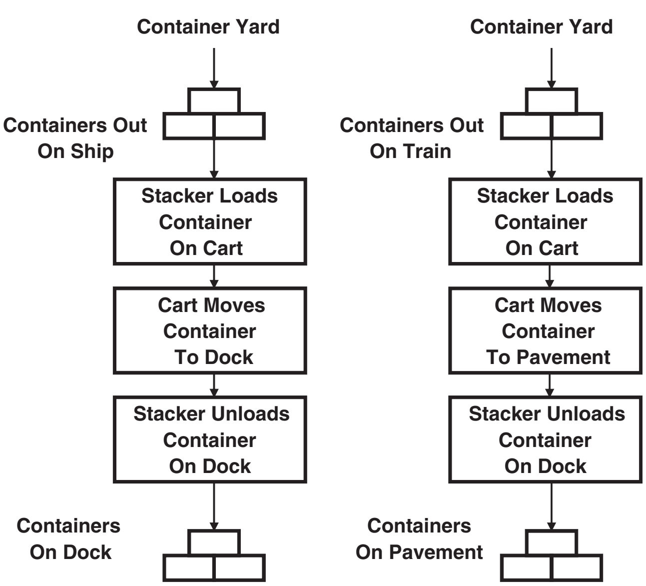

FIGURE 4 Simulation logic for moving containers from container yard to dock (Submodel E) and from yard to pavement (Submodel G).

Two types of inspections are simulated and shown in Figures 2 and 3. The first type of inspection is a quick tailgate inspection. This inspection consists only of opening the container to verify content.

The second inspection consists of an intensive inspection in which the container is opened and contents are removed, inspected, and repacked. It is assumed that each of these inspections includes an inspector to conduct the inspection and operate any required equipment. Therefore, inspection equipment utilization is equivalent to inspector utilization. In addition, inspectors are assigned to check the paperwork of entity arrivals. These inspections occur before any containers are unloaded.

Not all incoming containers are inspected. Some containers are designated C-TPAT (Customs Trade Partnership Against Terrorism) and certified safe by U.S. Customs and are transported directly by carts to the container yard. The companies shipping under a C-TPAT designation have been through a rigorous review of procedures and processes to earn the C-TPAT designation.

The terminal simulation model uses ship berths, ship cranes, train slots, train cranes, truck slots, stackers, carts, inspectors, tailgate inspection stations, and intensive inspection stations as resources. The inspectors check all paperwork on incoming ships, trains, and trucks and inspect containers arriving on trucks. It is assumed that an operator is placed at each tailgate inspection and intensive inspection station. The model has 13 entity attributes, 20 global variables, 78 activity blocks, and 11 entity blocks.

MODEL INPUT

The input data for Run 1 are given in Tables 1 through 4. Because the container terminal is currently undergoing a major expansion, much of the data for this study were based on existing operations, which are not necessarily the same processes that will be used in the new, expanded operation. Modifications were made to existing operational data by reviewing operational data from similar container port operations.

The decision to use the triangular distributions was made to greatly reduce the data collection effort because the triangular distribution is an acceptable approximation of many distributions. Data for the triangular distributions can be rapidly collected by interviewing individuals that are knowledgeable about the process. In the interview process three questions are asked of the process expert. The first parameter of the distribution is the lowest value, and the third parameter is the largest value. The middle parameter is the mean value or the most likely value. For example, to determine the containers leaving on a ship, the following questions are asked. What is the smallest number of containers leaving on a ship? What is the largest number of containers? What is the typical (or average) number

TABLE 1 Movement of Containers

	Containers Out		
Containers in	Ship (%)	Truck (%)	Train (%)
Ship		10	90
Truck	70		30
Train	80	2	18

TABLE 2 Container Inspections and Entity Parameters

	Ship	Train	Truck
% inspected	85%	85%	90%
Tailgate inspection (of 85%)	98%	98%	100%
Time of tailgate inspection (min)	T(6,8,10)	T(6,8,10)	3
Intensive inspection (of 85%)	2%	2%	
Time of intensive inspection (min)	T(240,300,360)	T(240,300,360)	
Time between arrivals (min)	T(1,320,1,440,1,560)	T(420,480,540)	T(2,080,2,320,2,560)
Containers in	T(400,450,500)	T(90,100,110)	
Containers out	T(200,250,300)	T(90,100,110)	T(90,100,110)

TABLE 3 Additional Entity Parameters

Entity	Time Between Arrivals (min)	Quantity in	Truck Leaves with No Containers (%)	Truck Leaves with Empty Container (%)	Truck Leaves with Full Container (%)
Truck with full container	T(54,60,66)	1	10	9	81
Empty truck	T(90,120,150)	0			100
Truck with empty container	T(180,240,300)	1	10	9	81

of containers? The triangular distribution is expressed in Tables 2 and 3 as T(a,b,c), where a is the minimum value, b is the mean value, and c is the maximum value. Table 1 presents the routing of containers in the terminal by percentage of activity. These data were from estimates made by dock personnel and based on anticipated container arrival and departure patterns.

Table 2 presents the container inspection data for each entity arrival. The inspection times were derived from dock personnel and vendors of the inspection equipment. Eighty-five percent of containers on ships and trains are inspected. Of the 85% of containers that were inspected, 98% go through the tailgate inspection station and 2% go through the intensive inspection station. Ninety percent of containers on trucks are inspected. Table 2 also presents the parameters for ship, train, and truck entities. The time between arrivals is based on estimated ship and train arrivals once the container facility is operational. The container arrivals and departures are also based on the capacities of these arrival entities. The time between ship arrivals follows the triangular distribution with parameters of 1,320 min, 1,440 min (mean), and 1,560 min. Likewise, the quantity of containers arriving and departing on ships and trains follows the triangular distributions.

TABLE 4 Experimental Design

Run	Inspectors	Tailgate Inspection Stations	Intensive Inspection Stations
Run 1	5	10	10
Run 2	3	10	10
Run 3	1	10	10
Run 4	1	8	10
Run 5	1	8	6
Run 6	1	8	5
Run 7	1	6	5
Run 8	1	6	4
Run 9	1	6	3
Run 10	1	5	3

Table 3 presents the parameters for the truck arrivals. The time between arrivals is based on estimated truck arrivals once the container facility is operational. The container arrivals and departures are also based on the capacities of these arrival entities. Ten percent of the trucks that arrive with a full container, or that arrive with an empty container, leave with no container, 9% leave with an empty container, and the remaining 81% leave with another full container. One hundred percent of the empty truck arrivals leave with a full container.

In addition to the data presented in Tables 1 through 3, the baseline input data for the model consisted of

- Two ship berths for unloading and loading containers;
- Two train terminals 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 ships;
- Two train cranes for unloading and loading containers from trains;
- Twelve stackers for unloading and loading containers from trucks to, and from, carts;
- Thirty carts for moving containers throughout the terminal;
- Two minutes to unload or load a container from ship, train, or truck;
- T(15,20,25) min to position a ship at a terminal (*T* = triangular distribution);
- T(15,20,25) min to position a train at a terminal;
- T(4,5,6) min to position a truck for unloading or loading;
- Two minutes to process paperwork to load a ship, train, or truck;
- T(4,5,6) min for ship, train, or truck to exit terminal;
- Two minutes to unload and load a cart;
- T(9,10,11) min for inspector to check paperwork for ship or train;

- T(4,5,6) min to position truck in container yard;
- T(2,3,4) min for inspector to inspect paperwork and container from truck;
- T(2,3,4) min for cart to move container from dock or pavement to inspection area;
- T(2,3,4) min for cart to move container from inspection area to container yard; and
- T(4,5,6) min for cart to move container directly from dock or pavement to container yard.

All the times to load, unload, and move containers on ship, train, and truck arrivals were derived from logbooks. The container inspection times were from discussion with dock personnel and vendors of the inspection equipment.

EXPERIMENTAL DESIGN

A previous simulation run with no container inspection, described in Schroer et al., is used as the baseline for this research (*11*). The simulation model from Schroer et al. was modified to include the container inspection logic (*11*). All the input data remained identical to the baseline run. Table 4 displays the experimental design. The basic concept of the design was to start the model with a large number of inspectors and inspection stations and to then reduce these resources in subsequent runs until there is an impact on the operation of the intermodal center. This impact was measured in regard to the reduction in the number of ships and trains through the intermodal center.

In simulation Runs 1 through 3 the number of inspectors was reduced from five to three and then to one. In Runs 4 through 10 the quantity of inspection stations was reduced from 10 tailgate inspection stations and 10 intensive inspection stations (Run 3) to five tailgate inspection stations and three extensive inspection stations. The simulation model was run for 1,440 h, or 180 eight-hour days, which is 6 months.

RESULTS

The results of the simulation runs are given in Tables 5 through 7. Table 5 shows results for Runs 1 through 6, for which the number of inspectors was reduced from five to three and then to one. Note that a reduction in the number of inspectors did not affect the entity throughput of the terminal. The number of tailgate inspection stations was reduced from 10 for Run 3 to eight for Runs 4 through 6, and

TABLE 5 Simulation Results for Runs 1 Through 6

	Run 1		Run 2		Run 3	
Resource	Quantity	Utilization (%)	Quantity	Utilization (%)	Quantity	Utilization (%)
Tailgate inspection stations	10	35	10	35	10	35
Intensive inspection stations	10	23	10	23	10	23
Inspectors	5	1	3	3	1	7
Carts	30	52	30	52	30	53
Entities Through Terminal	Quantity	Time in Terminal (min)	Quantity	Time in Terminal (min)	Quantity	Time in Terminal (min)
Ships	58	2,029	58	2,029	59	2,028
Trains	179	685	179	685	179	687
Empty trains	38	418	38	418	38	415
Trucks	1,441	33	1,441	33	1,440	33
Empty trucks	721	21	721	21	718	21
	Run 4		Run 5		Run 6	
Resource	Quantity	Utilization (%)	Quantity	Utilization (%)	Quantity	Utilization (%)
Tailgate inspection stations	8	44	8	44	8	44
Intensive inspection stations	10	26	6	40	5	48
Inspectors	1	7	1	7	1	7
Carts	30	54	30	53	30	53
Entities Through Terminal	Quantity	Time in Terminal (min)	Quantity	Time in Terminal (min)	Quantity	Time in Terminal (min)
Ships	59	2,034	59	1,996	59	2,032
Trains	178	692	178	690	179	690
Empty trains	37	419	38	425	38	421
Trucks	1,438	33	1,442	33	1,441	33
Empty trucks	714	21	720	21	716	21

TABLE 6 Simulation Results for Runs 7 Through 10

Resource	Run 7 Quantity	Run 7 Utilization (%)	Run 8 Quantity	Run 8 Utilization (%)	Run 9 Quantity	Run 9 Utilization (%)	Run 10 Quantity	Run 10 Utilization (%)
Tailgate inspection stations	6	60	6	70	6	59	5	49
Intensive inspection stations	5	47	4	60	3	83	3	53
Inspectors	1	8	1	7	1	7	1	37
Carts	30	53	30	54	30	60	30	71
Entities Through Terminal	**Quantity**	**Time in Terminal (min)**	**Quantity**	**Time in Terminal (min)**	**Quantity**	**Time in Terminal (min)**	**Quantity**	**Time in Terminal (min)**
Ships	59	2,048	59	2,001	59	2,076	41	2,007
Trains	180	693	178	696	178	689	123	686
Empty trains	38	423	37	443	38	411	37	423
Trucks	1,441	33	1,440	33	1,441	33	984	33
Empty trucks	724	21	720	21	718	21	494	21

the number of intensive inspection stations was reduced from 10 for Run 4 to six for Run 5 and five for Run 6. Again a reduction in the number of inspection stations did not affect the throughput quantity of entities at the terminal.

Table 6 gives the results for Runs 7 through 10, for which the number of tailgate inspection stations was reduced from six for Runs 7 through 9 to five for Run 10 and the number of intensive inspection stations was reduced from five for Run 7 to four for Run 8 and to three for Runs 9 through 10. Again a reduction in the number of inspection stations did not affect entity throughput of the terminal for Runs 7 through 9.

However, the number of ships through the terminal dropped significantly from 59 for Run 9 to 41 for Run 10, a reduction of 30%. The number of trains through the terminal dropped from 178 for Run 9 to 123 for Run 10, a reduction of 30%. The number of trucks through the terminal dropped from 1,441 for Run 9 to 984 for Run 10, a reduction of 31%.

Utilization of the tailgate inspection stations dropped from 59% for Run 9 to 49% for Run 10, and the intensive inspection stations dropped from 83% for Run 9 to 53% for Run 10. However, the utilization of inspectors increased from 7% for Run 9 to 37% for Run 10, and carts from 60% for Run 9 to 71% for Run 10.

Table 7 shows the utilization of the remaining resources. Ship crane utilization dropped from 67% for Run 9 to 46% for Run 10, and train crane utilization from 72% for Run 9 to 51% for Run 10. Also truck slot utilization increased from 4% for Run 9 to 34% for Run 10, and stacker utilization increased from 35% for Run 9 to 55% for Run 10.

As previously stated, entity throughput remained constant until Run 10. The number of tailgate inspection stations was reduced from six for Run 9 to five for Run 10. These results indicate that given the current entity arrival rates, inspection rates, and inspection times, the optimum inspection resources are six tailgate inspection stations, three intensive inspection stations, and one inspector.

The simulation results suggest that the reduction to five tailgate inspection stations in Run 10 resulted in a cascading effect on the utilization of various resources. For example, containers on the carts had to wait longer for service because of the fewer tailgate inspection stations. Therefore cart utilization increased to 71% for Run 10 as compared with 60% for Run 9. The reason for this increase in utilization is discussed in the following paragraph. Because cart utilization increased, the stackers had to wait until the carts became available. The stacker is captured before seizing a cart; therefore, the stacker utilization increased to 55% for Run 10 as compared with 35% for Run 9, which is discussed in the following paragraph. Furthermore, the inspector for truck containers had to wait for a stacker. The inspector utilization increased to 37% for Run 10 as compared with 7% for Run 9.

The use of the ProcessModel commands of GET and FREE greatly affected the interpretation of the resource utilizations. For example, the ProcessModel logic for loading and moving carts is to first GET a stacker and then GET a cart. Therefore, if a cart is not available

TABLE 7 Other Resource Utilizations

Resources	Quantity	Run 1 (%)	Run 2 (%)	Run 3 (%)	Run 4 (%)	Run 5 (%)	Run 6 (%)	Run 7 (%)	Run 8 (%)	Run 9 (%)	Run 10 (%)
Ship berths	2	68	68	68	68	67	68	69	67	70	77
Ship cranes	2	67	67	67	67	66	67	67	67	67	46
Tugs	2	1	1	1	1	1	1	1	1	1	1
Train slots	2	71	72	71	71	71	71	72	71	71	80
Train cranes	2	72	72	72	72	72	72	73	72	72	51
Truck slots	20	4	4	4	4	4	4	4	4	4	34
Stackers	12	34	34	35	35	34	35	35	35	35	55

the stacker waits. Because the stacker has already been seized (using GET), the utilization will increase. The stacker wait time is then included in its utilization. The ProcessModel logic for truck inspectors is to first GET the inspector and then GET a stacker. If the stacker is not available, the inspector waits. Because the inspector has already been seized (using GET), the utilization will increase. The inspector wait time is then included in its utilization. For optimal performance both resources must be available when the GET command is executed.

A reduction in the available empty carts resulted in fewer containers on the dock for loading onto ships and on the pavement for loading onto trains. As a result, the number of ships and trains through the terminal decreased. At the same time the utilization of ship berths and train slots increased because the ships were not exiting the terminal. Because the ships and cranes were waiting for containers, the utilization of the ship and train cranes decreased. Ship crane utilization decreased to 46% for Run 10 as compared with 67% for Run 9, and train crane utilization decreased to 51% for Run 10 as compared with 72% for Run 9.

SENSITIVITY ANALYSIS

The objective of this research was to determine the resources necessary to minimize the disruptions to port operations as a result of increased security inspection of containers. Run 9, with six tailgate inspection stations and three intensive inspection stations, met the stated objective. However, Run 10 with one less tailgate inspection station caused a significant reduction in ship, train, and truck throughput.

An analysis of the data suggests that one of the primary factors affecting entity throughput may be the number of carts that move containers between the container yard and the ship and train docks. Therefore, Run 11 was performed with 10 additional carts and the same number of inspection stations as Run 10. Entity throughput returned to the same levels as Run 9. Utilization of resources also returned to the same levels as Run 9. Cart utilization dropped to 46% as from 71% for Run 10. Therefore, it appears there is an economic trade-off between the number of carts and inspection resources. However, there are limits between these two resources.

Results in Tables 6 and 7 suggest that the container terminal may be at capacity when the inspection resources are reduced to the levels in Run 9. However, as shown by Run 11 with 10 additional carts and the same number of inspection stations as Run 10, the same capacity as for Run 9 can be achieved with one less inspection station resource.

A further look at results suggests that the arrival rates for ships and trains may be at maximum given the berth and crane resources. That is supported by the relatively high utilizations of 70% for ship berths, 67% for ship cranes, 71% for train slots, and 72% for train cranes. However the container facility may be able to handle additional truck arrivals provided that sufficient containers are available. This is supported by the low utilization of only 4% for truck slots.

There is significant sensitivity to the interdependency between entity arrivals (especially ship and train arrivals) and the number of containers arriving on these entities. An increase in ship arrivals increases incoming containers; however, it may not increase departing containers unless there are train and truck arrivals to take containers out of the facility. With this is the need for sufficient resources to load, unload, and move these containers.

One area of less sensitivity is tugboats. With one tug the utilization was 1%. However, one tug is very critical to overall terminal operations because it must be immediately available when a ship arrives or is ready to depart.

The number of stacker resources was constant at 12 for all runs. Further sensitivity analysis indicates that the number of stackers could probably be reduced without an impact on container throughput.

The resource utilization results are rather confusing for this container model. In most simulations high utilizations can signify potential bottlenecks or that the system is near capacity. Most of these systems have very constant and steady arrival rates. However, with container terminal simulations, low resource utilizations may still indicate that the system is near capacity. An arrival of a container ship requires a number of immediate resources, such as a berth and crane to unload containers and stackers and carts to move containers from the yard to the dock for loading. While the ship is in port these resources are at 100% utilization. After the ship leaves the terminal, these resources are idle. The unavailability of just one of these resources will significantly affect container throughput. Depending on the data input it is possible to have an increase in resource utilization or increases in entity arrivals and at the same time have a decrease in container throughput.

This coupling and interaction of resources and activities can result in misinterpretations and misunderstanding of the simulation results. Quite often what is obvious to increase container throughput is not true because of a second- or third-order effect that is buried in these complex interactions.

OTHER MODEL USES

The conceptual framework that was used in developing this container model has permitted the model to be readily modified for other needs of port managers (*6*). Several examples of these model modifications are

- Evaluating the impact of opportunities for improving processes and for minimizing wastes at the coal terminal at the port of Mobile (*7*). Simulation is valuable in evaluating proposed improvements before significant time and resources are expended. It is critical to understand the impact of changes in port operations before the expending of resources, especially at a large-scale operation such as a coal terminal.
- Validating the design capacities of the expansion of the container terminal at the Alabama state docks (*10*). Of special interest were the utilization of the berths, cranes, and stackers and the maximum container throughput of the terminal.
- Evaluating the throughput versus anticipated demand and the resources available to meet anticipated growth for the International Intermodal Center in Huntsville, Alabama (*9*). The results of the simulation revealed that current throughput could be met with considerably fewer resources than originally estimated and with no reduction in container throughput.
- Evaluating the impact of various container inspection sampling plans on the operation of a seaport container terminal (*12*). One of the sampling plans that minimized disruption of the terminal operations consisted of decoupling the inspection stations from the unloading of containers. Containers are then inspected as an inspection station becomes available.

CONCLUSIONS

In summary the following conclusions are made:

- Given the currently defined intermodal center operation, the minimum number of inspection resources that will not negatively affect entity throughput are six tailgate inspection stations, three intensive inspection stations, and one general-purpose inspector.
- Each of the inspection stations required one operator, or inspector. Therefore, a total of 10 inspectors are necessary to minimize the impact of container inspections: six at tailgate inspection, three at intensive inspection, and one general inspector.
- Any slight change in terminal operations for Run 10 would have a definite negative impact on the required minimum inspection resources. For example, reducing the number of tailgate inspection stations by one in Run 10 caused a 30% reduction in ship throughput, a 30% reduction in train throughput, and a 31% reduction in truck throughput.
- The impact of increased container inspection can be minimized or even eliminated by an overabundance of inspectors and inspector stations. Therefore, trade-offs between inspector and inspector station cost must be made with the time entities that are at the terminal. Simulation results show that adding additional resources can basically eliminate any entity delays.
- The simulation model assumed that a small percentage (15%) of containers were not inspected because of C-TPAT designation and only a small percentage (2%) of containers required opening, stripping, and an intensive inspection. A small change in these percentages would have a significant impact on entity throughput.
- The number of carts for moving containers within the intermodal terminal may be a limiting factor when the number of inspection resources is reduced. An increase in the number of carts resulted in the need for fewer inspection resources (Run 11).

An interesting observation of the simulation results for Run 10 is the ProcessModel GET and FREE statements effect on resource utilizations. This feature highlights the need for a trained simulationist to interpret the simulation results. The sequence of seizing resources greatly affects simulation results and the interpretation of these results. As previously discussed intuition says that if throughput decreased in Run 10, cart utilization should also decrease. However, just the opposite occurred. The ProcessModel logic was GET stacker and then GET cart. If the model logic were GET cart and then GET stacker, the resource utilizations would have been different.

In conclusion, the security inspection of container terminal operations can be minimized by the correct allocation of inspection resources. In fact, the simulation results imply that delays resulting from inspections can be basically eliminated by an overallocation of resources. However, this may not be economically feasible. Therefore, there is a trade-off between the number of resources and the cost of these resources and the acceptable delays in terminal throughput. By using simulation these trade-offs can be readily evaluated and the acceptable resource allocation determined.

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