JOURNAL OF ADVANCED TRANSPORTATION
J. Adv. Transp. (2010)
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/atr.140

Simulation of an intermodal container center served by air, rail, and truck

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SUMMARY

This paper presents a simulation model to evaluate the operations of the container facility at the International Intermodal Center in Huntsville, AL. The simulation was used to determine if throughput can satisfy anticipated demand and if sufficient resources are available to meet anticipated growth in demand. The current throughput of the intermodal center can be met with considerably fewer resources than originally estimated and with no reduction in container throughput. Furthermore, the container throughput can be increased considerably without any deterioration in entity times at the terminal. Included in the paper are a description of the conceptual framework, the simulation model written in ProcessModel, an analysis of the simulation results, and conclusions. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: intermodal center, containers, air, truck, rail, logistics, discrete event simulation

1. INTRODUCTION

Over 90% of cargo currently transported worldwide is shipped as containerized cargo. In 2000, container port traffic at the three busiest ports in the United States was 4.9 million TEUs (20-foot equivalent units) at Los Angeles, 4.6 million TEUs at Long Beach, and 1.6 million at Charleston, shown n Figure 1. The volume of containerized cargo essentially doubled at the ports of Los Angeles and Long Beach and greatly increased at most other ports by 2006, as shown in Figure 2. As the use of containerized cargo increases, the ports throughout the United States are improving operations and undergoing major expansions. The increase in containerized cargo is also impacting inland intermodal centers. The International Intermodal Center in Huntsville, AL is also experiencing growth and is currently planning an expansion.

Simulation offers an inexpensive approach to analyzing the operations of an intermodal center and to evaluate various operational alternatives before finalizing the design of any planned expansion. The two primary questions answered by the simulation were: (1) can container throughput satisfy anticipated demand? and (2) are resources sufficient to support anticipated growth in demand?

2. RELATED WORK

The literature contains many articles on the application of simulation for freight movement and logistics. Several of the articles specifically related to this paper are discussed in the following paragraphs. Gunther and Kim [1] have edited a book containing a number of articles on the simulation

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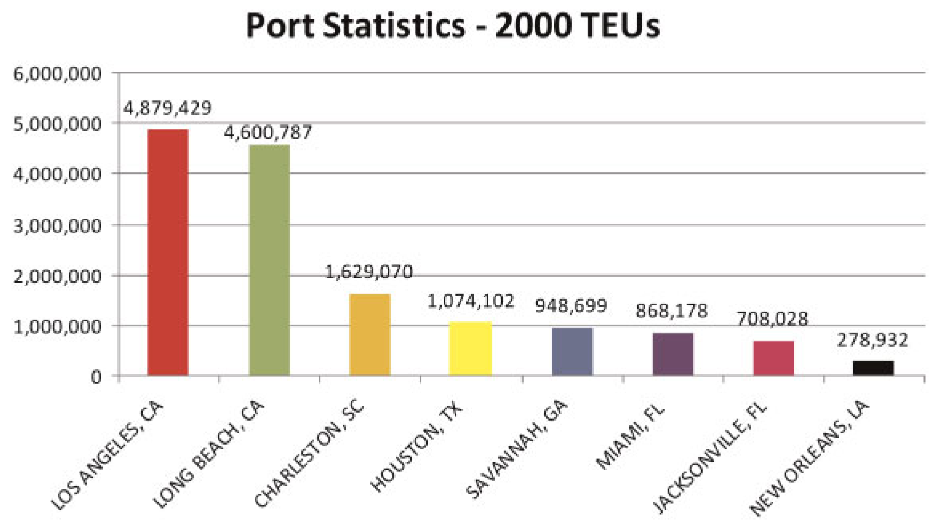

Figure 1. Selected port statistics 2000.

of container terminals. One of the articles by Rizzoli *et al.* [2] presents a simulation tool for modeling container activity *via* rail and truck at an intermodal terminal.

Kondratowicz [3] developed a generalized methodology called TRANSNODE for modeling and simulating intermodal freight transportation systems at seaports and inland terminals. Bruzzone *et al.* [4] outlined the evolution for applying simulation at multimodal container terminals.

Kulick and Sawyer [5] developed a simulation-based capacity analysis platform (SIMCAP) for analyzing intermodal terminal operations with emphasis on truck, rail, and yard capacity. Sarosky and Wilcox [6] describe the design and application of a SLAMSYSTEM model for an intermodal freight terminal.

Rida *et al.* [7] outlined a container terminal simulation model and the component architecture implemented in Java. The goal of the project was a decision support system to provide adequate strategy for increased traffic at ports. Parola and Sciomachen [8] developed a discrete event simulation approach for modeling the logistics supply chain system of a northwestern Italian port.

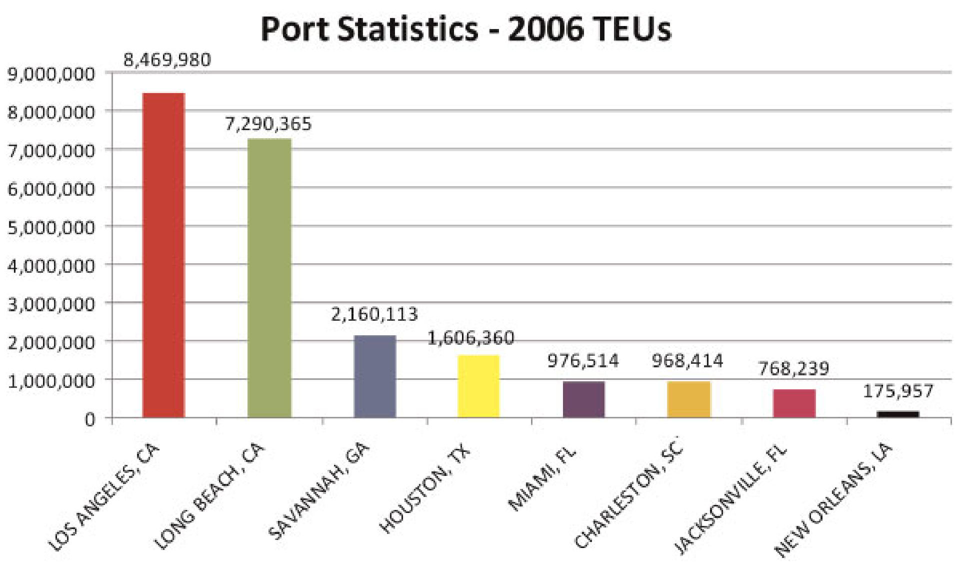

Figure 2. Selected port statistics 2006.

DOI: 10.1002/atr

Ottjes and Veeke [9] developed a simulation as part of the short-sea shipping effort supported by the European Commission. The innovative terminal concept they examined allows horizontal loading and unloading of seagoing ships by Automatic Guided Vehicles (AGVs) with expeditious throughput and short in-port times.

Gambardella *et al.* [10] developed a decision support system for the management of an intermodal container terminal with emphasis on spatial allocation of containers in the terminal yard, allocation of resources, and scheduling of operations to maximize performance based on economic indicators.

Zaffalon *et al.* [11] developed a discrete event simulation with resolution to the single container level to validate resource allocations and scheduling policies. Kulick and Sawyer [12] used simulation to analyze intermodal capacity issues including resources such as cranes, hostlers and side loaders; infrastructure, layout, and networks; forecasted demands; arrival and departure schedules; and tactical operation rules.

Dessouky and Leachman [13] developed a simulation methodology for analyzing complex rail networks from downtown Los Angeles to the San Pedro Bay Ports. Included in the study were the compound delays and ripple effects from conflicts of complex junctions, terminals, and railroad–railroad crossings.

Harris *et al.* [14] developed a simulation model of a major expansion of the container terminal at the Alabama State Docks in Mobile, AL. Harris *et al.* [15] have also developed a simulation model of a coal terminal at the State Docks. The coal terminal model was used to evaluate the results of a number of continuous improvement activities, or Kaizens [16], at the State Docks. These two models were constructed using the modeling environment for simulating seaports [17].

3. INTERMODAL CENTER

The International Intermodal Center (IIC) is located at the Huntsville International Airport between Huntsville and Decatur, Alabama on Interstate 565 approximately 10 miles from Interstate 65, which is designated as a Freight Significant Corridor by the Federal Highway Administration. Figure 3 contains several photographs of the IIC. The IIC is served by CSX Railroad and operates its own Class 3 Rail Service to move container car pulls to and from the main line.

It should be noted that no containers such as those on trains or trucks go onto cargo aircraft. Cargo aircraft use air cargo boxes that are configured to the shape of the aircraft.

These air cargo boxes may or may not contain pallets and are unpacked before the contents are cross-docked and put onto trucks. For simulation purposes the air cargo box is considered as a unit of freight (a simulation entity) with the content placed directly onto a truck. Similarly, no containers that arrive by truck or train are put on an aircraft. Air cargo is delivered to the intermodal center by truck as pallets or cases. For simulation purposes these pallets or cases that arrive on a truck are considered a container. Very infrequently air cargo also arrives by train as pallets or even containers. For simulation purposes these pallets or containers are considered a unit of freight (a simulation entity).

Figure 4 presents a diagram of the movement of containerized freight through the IIC. Freight moves from airplanes to trucks, trucks to airplanes, trucks to rail, rail to trucks and can go from rail to airplane (but this is very rare).

Table I summarizes the arrival and departure of containers on airplanes, trains, and trucks. For example, containers, or cargo boxes, that arrive on airplanes only depart on trucks.

4. SIMULATION MODEL

Figure 5 is a representation of the conceptual framework for the model development [17]. The conceptual framework consists of a number of independent, but linked, submodels. Each model has its own data input and entities with specific attributes. Within the conceptual framework, data are shared between the submodels through global variables. The content of the global variables can be altered within 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, branching logic, and updating entity attributes.

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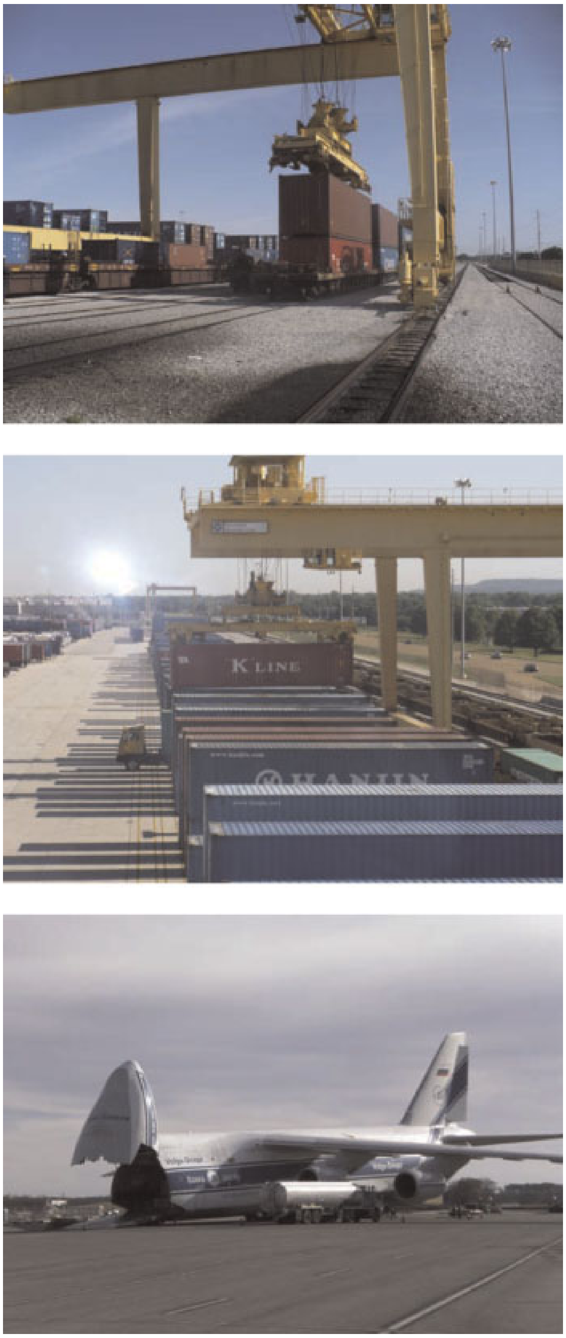

Figure 3. International Intermodal Center.

To assist in the model verification and validation, the conceptual framework includes a set of output blocks that display the current values of the global variables during the running of the simulation. These values are generally overlaid on top of the simulation model so the user can observe the movement of entities as well as any bottlenecks.

ProcessModel [18] was selected to implement the conceptual framework. The building blocks in ProcessModel were ideal for constructing the submodels. ProcessModel has four building blocks: activities, entities, resources, and stores. Within each block and for each routing option (connecting line) there is the capability of adding complex logic. Global variables and entity attributes can be easily defined within ProcessModel. ProcessModel also has a Label Block (shown

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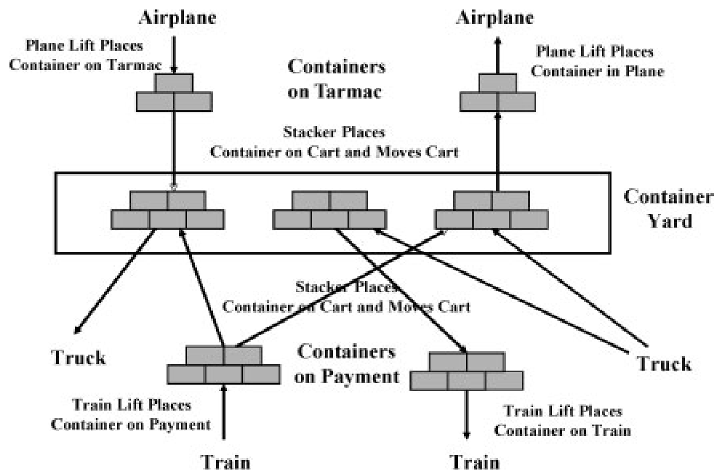

Figure 4. Container flow at Huntsville Intermodal Center.

Table I. Container arrivals and departures at intermodal center (Note 6).

Containers arrive on	Containers depart on		
	Airplane	Train	Truck
Airplane	NO	NO	YES (1)
Train	YES (4)	YES (5)	YES (5)
Truck	YES (2)	YES (3)	NO

Note: (1) Cargo box arriving on airplane and leaving on truck. (2) Pallet or case arriving on truck and leaving on airplane. (3) TEU arriving on truck and leaving on train. (4) Pallet or case arriving by train and leaving on airplane. (5) TEU arriving by train and leaving by truck or train. (6) Container, or unit of freight, in the simulation can be a cargo box, pallet or case, or TEU.

in Figure 5) that can be used to display the current content of selected global variables during the simulation.

Translating the container unloading and loading outlined in Figure 2 into the conceptual framework resulted in the following submodels:

- Planes unloading and loading of containers (entity = plane)
- Trains unloading and loading of containers (entity = train)

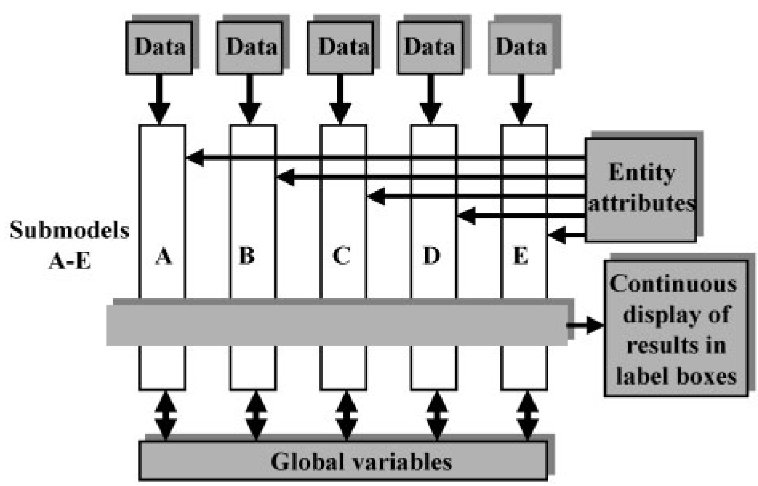

Figure 5. Conceptual framework.

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- Trucks unloading and loading of containers (entities = truck, empty truck, and empty truck with container)
- Movement of containers from plane tarmac to container yard (entity = move order1)
- Movement of containers from container yard to plane tarmac (entity = move order2)
- Movement of containers from train payment to container yard (entity = move order3)
- Movement of containers from container yard to train payment (entity = move order4)

Resources resident in the intermodal terminal include plane terminals, train terminals, truck slots, plane lifts, train lifts, stackers, and carts. The plane and train lifts are similar to fork lifts or side loaders for unloading and loading containers. The model has 13 entity attributes, 20 global variables, 64 activity blocks, and nine entity blocks. Figure 6 displays the ProcessModel for the plane unloading/loading submodel. The comments next to the blocks and lines are the imbedded logic within the ProcessModel blocks and connecting lines.

5. MODEL VERIFICATION AND VALIDATION

Model verification is determining if the model is correctly represented in the simulation code.

Model validation is determining if the model is an accurate representation of the real world system.

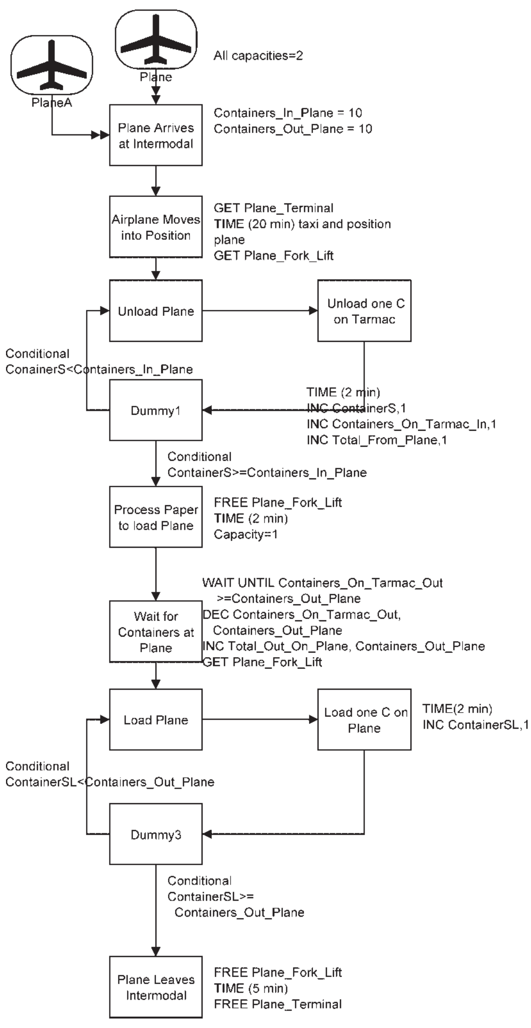

Figure 6. ProcessModel for airplanes.

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Table II. Label block values from simulation.

	Plane	Train	Truck	Total
Full containers in	1800	4500	2160	8460
Full containers out	1800	3600	2611	8011
Containers waiting for	200	198	51	449

ProcessModel provides the capability in a Label Block to display data from the global variables during the simulation. By reducing the speed at which the simulation runs, it is possible to observe these values as the entities move through the simulation.

The model was run for 1440 hours, or 180 eight-hour days, which closely equates to 6 months. Table II presents the values that were recorded in the ProcessModel label boxes at the end of the simulation.

The full containers in (8460) minus the full containers out (8011) should equal the containers in the intermodal center at the end of the simulation (449).

The actual lifts, either a container load or unload, at the intermodal center for 2005 were 34 410. The simulation results for 6 months were 9180 + 8267 + 913, or 18 360 lifts (See Table VIII). On an annual basis, this equates to 36 720 lifts, which compares favorably to the actual lifts of 34 400 in 2005.

6. EXPERIMENTAL DESIGN

The experimental design is given in Table III. The current intermodal center operations are defined in Baseline Run1. Each following simulation run was based upon the output from the previous run. Resources were reduced for each successive simulation run and defined as Runs2–10. Each run, with fewer resources by continuing reducing the number of plane and train terminals, truck slots, plane and train lifts, stackers and carts, was evaluated against the Baseline Run1.

The number of plane, train, and truck entity arrivals was increased from Run10 to 11. Runs12–15 evaluated Run11 with fewer resources by continuing decreasing the number of plane and train terminals, truck slots, plane and train lifts, stackers, and carts.

7. BASELINE MODEL

The input data for Baseline Run1 are given in Tables IV and V. In addition, the baseline input consisted of

Table III. Experimental design.

Experiment	Description
Baseline Run1	Current intermodal center operations
Runs2–10	Multiple runs reducing the number of resources from Baseline Run1based upon the output of the previous run
Run11	Increased number of entity arrivals in Run10
Runs12–15	Multiple runs reducing the number of resources in Run11

Table IV. Movement of containers.

Containers in	Containers out		
	Plane (%)	Truck (%)	Train (%)
Plane	0	100	0
Truck	40	0	60
Train	25	55	20

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Table V. Entities.

Entity	Time between arrivals (minute)	Average containers in	Average containers out		
Plane	480	10	10	0	0
Train	960	50	40	0	0
			Truck leaves with no containers	Truck leaves with container	Truck leaves with full container
Truck with full container	40	1	10%	9%	81%
Empty truck	240	0	0	0	100%
Truck with empty container	120	1	10%	9%	81%

- two plane terminals for unloading and loading containers;
- three train terminals for unloading and loading containers;
- maximum 20 trucks in intermodal center at one time;
- two lifts for unloading and loading containers from planes;
- two lifts for unloading and loading containers from trains;
- eight stackers for unloading and loading containers from trucks and onto carts;
- twenty carts for moving containers throughout the center;
- 2 minutes to unload or load a container from plane, train, or truck;
- 20 minutes to position a plane at a terminal;
- 20 minutes to position a train at a terminal;
- 5 minutes to position a truck for unloading or loading;
- 2 minutes to process paperwork to load a plane, train or truck;
- 5 minutes for plane, train, or truck to exit intermodal center;
- 2 minutes to unload and load a cart;
- 5 minutes to move a cart between a plane, train or truck, and the container yard.

Triangular distributions were used for all the service times. These times remained the same as well as the percentage routings of the entities for all the simulation runs. The only changes in the data were the number of resources and the time between arrivals of the plane, train, and truck entities. Triangular distributions are three parameter distributions $T(a, b, c)$ where a is the smallest value, b the mean value, and c the largest value. In collecting data, it is rather easy to ask staff working at an operation for the minimum, most likely, and maximum values for any variable. A triangular distribution is a close approximation to the normal distribution with the exception of the infinite tails for the normal distribution.

The results of Baseline Run1 are given in Tables VI–VIII. Table VI presents the number of entities that pass through the intermodal center after running the simulation for 1440 hours or 6 months. The average entity wait times were relative low indicating adequate resources to unload and load all entity arrivals. These waiting times include the time an entity waited on the appropriate container or waited on an available resource.

Table VII shows the per cent utilization of the resources. The relative low utilizations indicate that there is an excess of resources at the intermodal center. It should be noted that the average utilizations might be misleading. For example, when a plane arrives, the plane terminal and plane lifts are busy

Table VI. Entities through intermodal center for Baseline Run1.

Entity	Quantity through IIC	Avg. time in IIC (minute)	Avg. value added time (minute)	Avg. wait time (minute)
Planes	180	94	67	27
Trains	90	326	207	119
Trucks	2160	43	14	29
Empty trucks	360	36	12	24
Truck with empty container	720	39	14	25

DOI: 10.1002/atr

Table VII. Utilization of resources for Baseline Run1.

Resource	Quantity	Utilization (%)
Plane terminals	2	9
Train terminals	3	11
Truck slots	20	7
Plane lifts	2	6
Train lifts	2	14
Stackers	8	13
Carts	20	7

until the plane is unloaded and loaded. Once the plane leaves the intermodal center these resources become idle.

Table VIII provides a summary of the container activity during the simulation run. A total of 9180 containers were unloaded, 8267 containers were loaded, and 913 containers were still at the intermodal center. Of these 913 containers 200 were on the tarmac waiting to be loaded onto a plane, 198 containers were on the payment waiting to be loaded onto a train, 51 containers were in the container yard waiting to be loaded onto a truck, and 464 empty containers in the container yard.

8. REMOVAL OF RESOUCES FROM BASELINE RUN1

The relative low utilization of the resources in Table VII for Baseline Run1 indicates that there is an excess of resources at the intermodal center. Therefore, a number of additional runs were made with each run reducing a resource by one. For example, Run2 reduced the number of plane terminals from two to one and the simulation results compared with the Baseline Run1. The next two runs reduced the number of train terminals from three to two and then to one. In successive runs, the truck slots were reduced from 20 to 15 and then to 12. The plane lifts were reduced from two to one and the train lifts from two to one. The stackers were reduced from eight to six. Carts were reduced from 20 to 15 and then to 10. The final Run10 had the resources Shown in Table IX. A further reduction in the resources greatly increased the entity times at the intermodal center.

The results for Run10 are presented in Tables X–XII. Table X shows the entities through the intermodal center after running the model for 1440 hours. The Intermodal Center resources in Run10 are reduced by one half. Such a reduction in resources is significant because of the corresponding

Table VIII. Container activity for Baseline Run1.

Entity	Containers unloaded	Containers loaded	Containers in process
Planes	1800	1800	200
Trains	4500	3600	198
Trucks	2160	2611	51
Trucks with empty containers	720	256	464
Total	9180	8267	913

Table IX. Resources for Run10.

Resource	Quantity
Plane terminals	1
Train terminals	1
Truck slots	12
Plane lifts	1
Train lifts	1
Stackers	6
Carts	10

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Table X. Entities through intermodal center for Run10.

Entity	Quantity through intermodal	Avg. time in intermodal (minute)	Avg. value added time (minute)	Avg. wait time (minute)
Planes	180	99	67	32
Trains	90	371	207	164
Trucks	2160	28	14	14
Empty trucks	360	21	12	9
Trucks with empty container	720	27	14	13

reductions that would be experienced in repairs, maintenance, and overall operating costs. The quantities through the intermodal center were very close to the quantities for Baseline Run1 even after a number of resources were removed from the model. The average wait time for the train entity increased from 119 to 164 minutes. The other entity wait times did not significantly increase.

Table XI gives the utilization of the resources after running the model for 1440 hours. As expected the utilizations increased since there were fewer resources in Run10 as compared to Baseline Run1. Train terminal utilization increased from 11% for Baseline Run1 to 36% for Run10. Train lift utilization increased from 14% for Baseline Run1 to 28% for Run10.

Table XII presents the container activity during the simulation run. The total unloaded and loaded containers were almost identical to the results of Baseline Run1.

9. INCREASE IN ENTITY ARRIVALS

One of the questions this research is attempting to answer was the impact of additional entity arrivals on overall intermodal center operations. There is the possibility of a plane arrival every week from Asia. Currently a plane arrives daily from Europe. The addition of the plane from Asia requires additional truck and train arrivals to move the containers out, and to bring additional containers for shipment by plane. Table XIII gives the increase in entity arrivals (Run11). The bold values in the table reflect the changes to the entity input data originally presented in Table V.

The increase in entity arrivals should require additional resources. Even so, the number of resources was kept basically the same (See Table XIV) as the Baseline Run1, with the exception of train slots that was reduced to two rather than the original three.

The results for Run11 after running the model for 1440 hours are given in Tables XV–XVII. Table XV provides the entity times at the intermodal center. The average wait times remain relatively

Table XI. Utilization of resources for Run10.

Resource	Quantity	Utilization (%)
Plane terminals	1	20
Train terminals	1	36
Truck slots	12	5
Plane lifts	1	13
Train lifts	1	28
Stackers	6	17
Carts	10	15

Table XII. Container activity for Run10.

Entity	Containers unloaded	Containers loaded	Containers in process
Planes	1800	1800	196
Trains	4500	3600	188
Trucks	2160	2611	65
Trucks with empty containers	720	270	450
Total	9180	8281	899

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Table XIII. Increase in entity arrivals for Run11.

Entity	Time between arrivals (minute)	Average containers in	Average containers out		
Plane-Europe	480	10	10	0	0
Plane-Asia	**2400**	10	10	0	0
Train	**720**	50	40	0	0
			Truck leaves with no container	Truck leaves with container	Truck leaves with full container
Truck with full container	**30**	1	10%	9%	81%
Truck empty	240	0	0	0	100%
Truck with empty container	120	1	10%	9%	81%

Table XIV. Resources for Run11.

Resource	Quantity
Plane terminals	2
Train terminals	2
Truck slots	20
Plane lifts	2
Train lifts	2
Stackers	8
Carts	20

Table XV. Entities through intermodal center for Run11.

Entity	Quantity through intermodal	Avg. time in intermodal (minute)	Avg. value added time (minute)	Avg. wait time (minute)
Planes-Europe	180	93	67	26
Planes-Asia	36	93	67	26
Trains	120	312	207	105
Trucks	2879	29	14	15
Empty trucks	360	21	12	9
Truck with empty container	720	27	14	13

low even after an increase in the arrivals of plane, train, and truck entities and were very similar to the Baseline Run1.

Table XVI gives the utilization of the resources for Run11. Note that the resources increased because of the increase in the entity arrivals. However, the utilizations were still relatively low. The utilization of the train terminals increased from 11% for the Baseline Run1 to 21% for Run11. This was anticipated since the train arrival times were lowered from 960 minutes for the Baseline Run1 to

Table XVI. Utilization of resources for Run11.

Resource	Quantity	Utilization (%)
Plane terminals	2	11
Train terminals	2	21
Truck slots	20	6
Plane lifts	2	8
Train lifts	2	18
Stackers	8	16
Carts	20	10

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Table XVII. Container activity for Run11.

Entity	Containers unloaded	Containers loaded	Containers in intermodal
Planes	2160	2160	544
Trains	6000	4800	257
Trucks	2880	3235	44
Trucks with empty containers	720	311	409
Total	11 760	10 506	1254

720 minutes for Run11 and the number of train slots was reduced by 33%. The increase in the truck arrivals did not increase truck slot utilization because of the large number of slots.

Table XVII gives the container activity for Run11. As a result of an increase in the entity arrival rates the container throughput increased to 23 520 (+28%) from 18 360 for Baseline Run1.

10. REMOVAL OF RESOURCES FROM REVISED MODEL

The relative low utilization of the resources indicates an excess of resources available. Therefore, a number of additional runs were made with each run a reduction in a resource by one. Additional runs (Runs12–15) were made with the final Run15 utilizing the resources given in Table XVIII. Further removal of resources greatly increased the entity times at the intermodal center.

The results for Run15 are given in Tables XIX–XXI after running the model for 1440 hours. Table XIX presents the entities through the intermodal center for Run15. Basically, the average entity times remained the same as for Run11. The exception was the time in the terminal for planes-Europe that increased to 111 minutes from 99 minutes for Run11. This increase in time can be attributed to the increase in entity planes-Asia.

Table XX shows the utilization of resources for Run15. The utilizations increased from Run11 due to the reduction in the number of resources available. However, the rate of increase was not as large. The utilization for the plane terminal increased from 11% for Run11 to 23% for Run15 because of the

Table XVIII. Resources for Run15.

Resource	Quantity
Plane terminals	1
Train terminals	2
Truck slots	12
Plane lifts	1
Train lifts	2
Stacker	8
Carts	12

Table XIX. Entities through intermodal center for Run15.

Entity	Quantity through intermodal	Avg. time in intermodal (minute)	Avg. value added time (minute)	Avg. wait time (minute)
Planes-Europe	180	111	67	44
Planes-Asia	36	93	67	26
Trains	120	312	207	105
Trucks	2879	32	14	18
Empty trucks	360	24	12	12
Truck with empty container	720	30	14	16

DOI: 10.1002/atr

Table XX. Utilization of resources for Run15.

Resource	Quantity	Utilization (%)
Plane terminals	1	23
Train terminals	2	21
Truck slots	12	7
Plane lifts	1	16
Train lifts	2	18
Stackers	8	16
Carts	12	16

Table XXI. Container activity for Run15.

Entity	Containers unloaded	Containers loaded	Containers in process
Planes	2160	2160	412
Trains	6000	4800	414
Trucks	2880	3219	35
Trucks with empty containers	720	321	399
Total	11 760	10 500	1260

plane arrivals from Asia. Likewise, the plane lifts increased from 8% for Run11 to 16% for Run15. The other resources did not significantly increase because the number of resources was similar to Run11.

Table XXI displays the resulting container activity for Run15. The containers unloaded and loaded remained identical to Run11 (23 520 lifts for both Runs11 and 15).

11. PLANNING FOR ADDITIONAL GROWTH

Lift capacity reached 47 040 annually for Run15 with fewer resources than in the Baseline Run1. The estimated 2007 container lifts is 45 000. Therefore, it may be possible to increase the number of lifts by restoring those resources in Runs11 and 15.

The results of the previous runs suggest that the intermodal center has the capacity for additional container throughput, especially because of the relative low utilization of resources. As a result, the experimental design shown in Table III was amended to include and additional run, Run16. Table XXII gives the revised time between arrivals for Run16.

Table XXII. Increase in entity arrivals (Run16).

Entity	Time between arrivals (minute) (Run16)	Time between arrivals (minute) (Run15)
Plane-Europe	360 (6 hours)	480
Plane-Asia	1200 (20 hours)	2400
Train	480 (8 hours)	720
Truck with full container	20	30
Empty truck	240 (4 hours)	240
Truck with empty container	120 (2 hours)	120
Resources		
Plane terminals	2	1
Train terminals	3	2
Truck slots	20	12
Plane lifts	2	1
Train lifts	2	2
Stackers	8	8
Carts	20	12

DOI: 10.1002/atr

Table XXIII. Entities through intermodal center for Run16.

Entity	Quantity through intermodal	Avg. time in intermodal (minute)	Avg. value added time (minute)	Avg. wait time (minute)
Planes-Europe	240	94	67	27
Planes-Asia	59	93	67	26
Trains	180	307	207	100
Trucks	4319	28	14	14
Empty trucks	360	21	12	9
Truck with empty container	720	27	14	13

The results of Run16 are given in Tables XXIII–XXV after running the simulation for 1440 hours. Table XXIII shows the entity times at the intermodal center. As anticipated, the quantity through the intermodal center increased for planes, trains, and trucks. Throughput for planes increased from 216 for Run15 to 299 (+38% increase) for Run16, for trains from 120 for Run15 to 180 (+50% increase) for Run16, and for trucks from 2879 for Run15 to 4319 (+50% increase) for Run16.

Even with this increase in throughput the average time an entity was at the intermodal center remained constant. The average time for planes-Europe was 111 minutes for Run15 and 94 minutes for Run16, for planes-Asia 93 minutes for Run15 and 93 minutes for Run16, for trains 312 minutes for Run15 and 307 for Run16, and for trucks 32 minutes for Run15 and 28 minutes for Run16. These results indicate that the additional resources were more than adequate to increase throughput while not causing longer delays for entities to exit the intermodal center.

Table XXIV presents the utilization of the resources for Run16. The train lifts and stackers were greater utilized as compared to Run15 (See Table XX). Run15 had two train lifts that were utilized 18% while for Run16 two train lifts were utilized 28%. Run15 had eights stackers that were utilized 16% while for Run16 the eight stackers were utilized 24%. On the other hand, Run15 had only one plane terminal that was utilized 23% while two plane terminals for Run16 were utilized 16%. Stacker utilization increased from 16% for Run15 to 24% for Run16.

Table XXV gives the container activity for Run16. Run16 had a significant increase in lifts as compared to Run15. Total containers unloaded were 17 030 (+45%) as compared to 11 760 for Run15. Total containers loaded were 15 020 (+44%) as compared to 10 500 for Run15. The number of

Table XXIV. Utilization of resources for Run16.

Resource	Quantity	Utilization (%)
Plane terminals	2	16
Train terminals	3	21
Truck slots	20	8
Plane lifts	2	11
Train lifts	2	28
Stackers	8	24
Carts	20	15

Table XXV. Container activity for Run16.

Entity	Containers unloaded	Containers loaded	Containers in intermodal
Planes	2990	2990	966
Trains	9000	7200	447
Trucks	4320	4370	336
Trucks with empty containers	720	460	260
Total	17 030	15 020	2009

DOI: 10.1002/atr

Table XXVI. Summary results.

	Baseline Run1	Fewer resources (Run10)	More entity arrivals (Run11)	Fewer resources (Run15)	More entity arrivals (Run16)
Annual container lifts (estimate)					
Unloaded	18 360	18 360	23 520	23 520	34 060
Loaded	16 534	16 562	21 012	21 000	30 040
In container yard	1826	1798	2508	2520	4018
Total lifts	26 720	36 720	47 040	47 040	68 118
Annual entities through intermodal center (estimate)					
Planes-Europe	360	360	360	360	480
Planes-Asia	NA	NA	72	72	118
Trains	180	180	240	240	360
Trucks	4320	4320	5758	5758	8638
Empty trucks	720	720	720	720	720
Truck with empty container	1440	1440	1440	1440	1440
Average time in intermodal center (minute)					
Planes-Europe	94	99	93	111	94
Planes-Asia	NA	NA	93	93	93
Trains	326	371	312	312	307
Trucks	43	28	29	32	28
Empty trucks	36	21	21	24	21
Trucks with empty containers	39	27	27	30	27
Resources/utilization					
Plane terminals	2/9%	1/20%	2/11%	1/23%	2/16%
Train terminals	3/11%	1/36%	2/21%	2/21%	3/21%
Truck slots	20/7%	12/5%	20/6%	12/7%	20/8%
Plane lifts	2/6%	1/13%	2/8%	1/16%	2/11%
Train lifts	2/14%	1/28%	2/18%	2/18%	2/28%
Stackers	8/13%	6/17%	8/16%	8/16%	8/24%
Carts	20/7%	10/15%	20/10%	12/16%	20/15%

containers in the intermodal center at the end of the simulation was 2009 (+59%) up from 1260 for Run15.

12. CONCLUSIONS

Table XXVI gives a comparison of the results from the Baseline Run1, 10, 11, 15, and 16. In summary the following conclusions are made:

- The current throughput (34 400 lifts in 2005) of the intermodal center can be met with considerably fewer resources than originally estimated for the Baseline Run1 and with no reduction in container throughput (Run10). The resources for Run10 were one plane terminal, one train terminal, 12 truck slots, one plane lift, one train lift, six stackers, and 10 carts. Annual lifts for Run10 were 36 720.
- The reduction in truck slots from 20 for the Baseline Run1–12 for Run10 indicates that only 12 trucks need to be inside the intermodal center at a time. This results in a considerably less space requirement and possibly fewer personnel.
- The container throughput can be increased considerably without any deterioration in entity times at the terminal. For Run15 the container throughput reached 47 040 lifts annually up from 36 720 for Run11. Consequently, entity times at the intermodal center remained relatively constant. For example, the average plane entity time was 93 minutes for Run11 and 111 minutes for Run15. The average train entity time was 312 minutes for Run11 and 312 minutes for Run15. The average truck entity time 29 minutes for Run11 and 32 minutes for Run15.
- Resource utilizations after reducing the number of resources were still relatively low. However, when the resources, such as stackers, was reduced below eight, the average entity times increased

DOI: 10.1002/atr

significantly because of higher waiting times for either a resource or a container. Future research may be warranted in using Overall Equipment Effectiveness (OEE) instead of equipment utilization as a measure.

- Run16 indicates that considerably more container traffic is possible with the existing resources from the Baseline Run1. Run16 indicates that these resources can process 68 118 lifts annually. This is a 51% increase over the projected 2007 container traffic of 45 000 lifts.
- Resource utilization is not a good measure of the utilization of resources during the simulation. For example, when a train arrives at the train terminal the train lifts are 100% busy. Then, after the train exits the intermodal center, these resources are idle. As a result, the average utilization is low.
- There is considerable interaction between the various submodels. Consequently, decreasing the time between arrivals of one entity might not increase container throughput. In fact, just the opposite might occur because the resources are now busy unloading an entity instead of loading another entity.

13. ABBREVIATIONS

The following symbols are used in this paper:

TEUs	20-foot equivalent units
AL	Alabama, U.S.A
IIC	International Intermodal Center, Huntsville, AL
T(a, b, c)	Triangular Distribution with a is the smallest value, b the mean value, and c the largest value
RUN##	indicates the sequence number of the simulation model run
OEE	Overall Equipment Effectiveness

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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