Modular Approach for Rapidly Developing Simulation Models for Analyzing and Evaluating Port Operations

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ABSTRACT
This paper presents a modular approach for rapidly developing simulation models that can analyze and evaluate existing port operations, changes and expansions. Simulation is an inexpensive insurance against costly mistakes involving capital expenditures, but many managers still perceive simulation to be a costly and time consuming option. The underlying purpose of this research has been the development of rapid reaction modular simulation that provides quick answers and is flexible enough to be used in multiple situations. Applications of this approach have been completed at the Alabama State Docks and the Huntsville International Intermodal Center where it has shown to be possible to rapidly construct the model in segments, one submodel at a time. Consequently, each submodel can be debugged and verified separately, thus reducing the overall development time. Included in this paper are a description of the modular modeling framework, descriptions of the five model application implementations and conclusions.

INTRODUCTION

Discrete event simulation is a powerful computer tool to analyze and evaluate systems and processes. Some companies will not launch a major expansion, change in a process, or capital expenditure until a detailed analysis is completed using simulation. Many users consider simulation as inexpensive insurance against costly mistakes especially when large capital expenditures are being considered [1].

Even with all the benefits of simulation there are difficulties that hinder the successful development and implementation of simulation models. This is especially true in obtaining management support because of preconceived ideas about the time and cost overruns on past simulation projects. The time to create, validate and verify a simulation project seems to be the most significant barrier to overcome. In many instances the data needed for a successful simulation do not exist. The data are generally not readily available in a form that can be easily used. Even then the available data are not credible, incomplete or inaccurate. Furthermore, in many instances there is not sufficient time to collect the data because of urgency from management for answers.

This paper addresses these critical issues, especially the time factor, to develop and verify and validate simulation models and the data collection efforts. Simulation models of port and terminal operations have become very valuable as decision support tools. It is critical to understand the impact of change prior to expending resources. This paper presents a modular approach for rapidly developing simulation models that can analyze and evaluate port planning and operations, changes in operations and capital expansions.

MODELING MODULAR FRAMEWORK

Figure 1 is the framework of the modular approach for developing simulation models of ports. The framework consists of a number of submodels that run independent of each other. Each submodel has its own data input and entities with specific attributes. For example, the data input can include arrival and service times, storage capacities and available resources.

In the modular approach data are shared between the submodels by global variables. The content of 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.

To assist in the verification and validation (V&V) the modular approach includes a set of output blocks, or labels, that display current values from 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.

A simplified and rapid approach to data collection is to ask the appropriate questions through interviews with personnel directly involved with the application. This is not only effective, but also a 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.

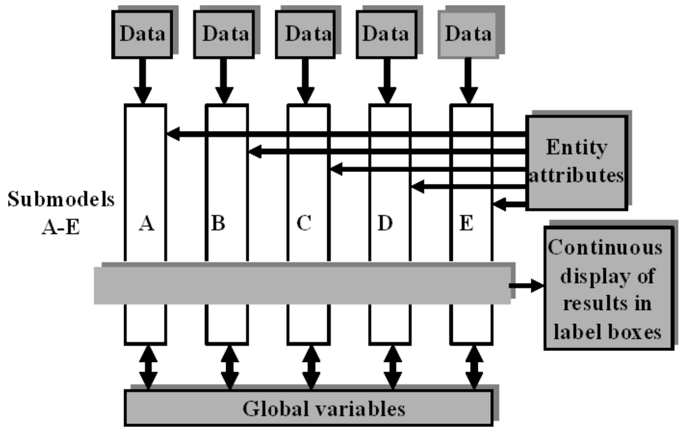

FIGURE 1 Overview of modular approach

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 (See Figure 2).

A reasonable assumption is that service times follow triangular distributions. It is rather easy to ask knowledgeable personnel the most frequent time or mode (parameter c), the smallest time (parameter a) and the largest time (parameter b) to obtain the needed parameters for the triangular distribution in Figure 2. The triangular distribution (probability density function) is a continuous distribution with a mode of c, a mean of $(a + b + c)/3$ and a variance of $(a2 + b2 + c2 - ab - ac - bc)/18$. The triangular distribution closely resembles the normal distribution if $(c - a) = (b - c)$. However, most data are skewed and more accurately represented by the log normal distribution. The triangular distribution in Figure 2 resembles the log normal since $(c - a) > (b - c)$. It should be noted that log normal distributions could have relatively long tails, which may or may not be desirable in the simulation.

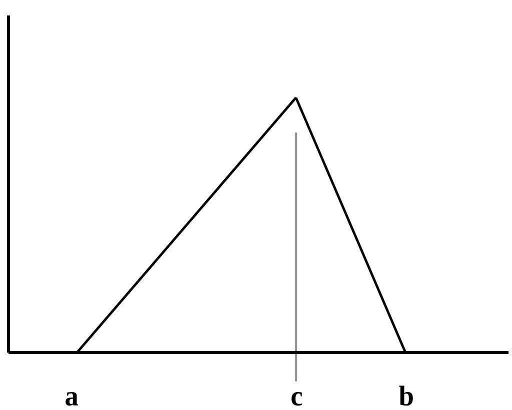

FIGURE 2 Triangular probability density function

MODELING SYSTEM

ProcessModel [2] was selected to implement the modular approach. ProcessModel is a commercially available discrete event simulation package. The building blocks in ProcessModel were ideal for constructing the submodels in the framework of the modular approach. ProcessModel has four building blocks: entities, activities, resources and stores. Entities are items (such as ships, trains and trucks) or people being processed. Activities are tasks performed on activities (such as unloading a ship or truck). Resources are agents used to perform activities and move entities (such as inspectors). Stores are stock spaces where entities wait for further processing.

Within each block type and for each routing option (connecting line) ProcessModel has the capability of adding very complex logic. Global variables and entity attributes can be easily defined within ProcessModel. ProcessModel also has a label block function that can be used to continually display the current content of selected global variables during the simulation. The label block function is an effective tool during model verification and validation.

The basic steps in constructing a ProcessModel following the modular approach are:

1. Define and name as many of the global variables, entity attributes, resources and output blocks as possible.
2. Construct each submodel, debug and verify and validate separately. The use of constants for all data input greatly reduces the debugging time as well as model verification. Before starting another submodel development the arrival of entities is turned off.
3. Add back entity arrivals into the submodels once all the submodels have been constructed.
4. Combined all submodels into one model and again verify and validate with distribution data.

APPLICATIONS OF MODULAR APPROACH

The following opportunity for application of this methodology have been implemented using the modular approach:

- Model 1 - Operations of a coal handling terminal
- Model 2 - Impact of continuous improvements on a coal terminal
- Model 3 - Expansion of a container terminal
- Model 4 - Impact of increased security inspections on a container terminal
- Model 5 - Operations of an intermodal center

Each of these applications is discussed in the following sections. An overview of each application is given followed by the use of the modular approach in constructing the simulation model and a summary of the significant results of the simulation.

MODEL 1 - OPERATIONS OF COAL HANDLING TERMINAL

The McDuffie Coal Terminal at the Alabama State Docks in Mobile, Alabama was established in 1976 as an export facility. The McDuffie Terminal consists of 556 acres and is the largest coal terminal on the gulf coast and the second largest in the U.S. In 1998, the facility began importing low sulfur coal for use at power generation plants. Total tonnage through the terminal for FY05 was 15.5 million tons. Total ground capacity is 2.3 million tons. Annual throughput capacity is 20 million tons. A major customer would like to see the throughput increased to 30 million tons annually. The modular approach was used to determine if the current resources could handle this increase in coal throughput.

Model

Figure 3 is the model of the McDuffie Coal Terminal [3]. Low sulfur coal arrives on ships and leaves on barges and trains. High sulfur coal arrives on barges and trains and leaves on ships. This series of activities are not unlike many other coal handling facilities [4] and thus this approach has potential applicability to many situations.

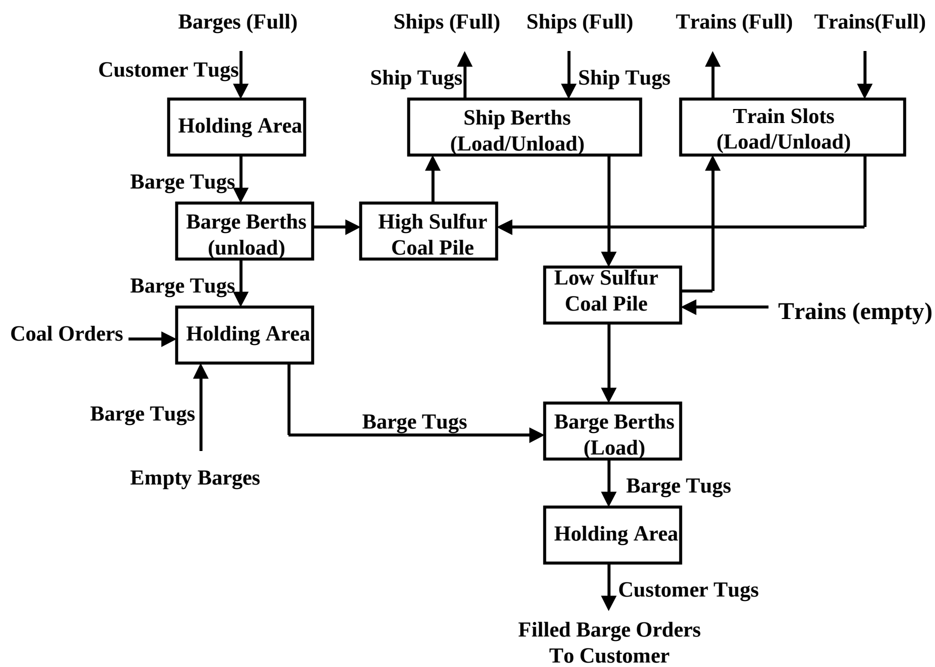

FIGURE 3 Coal terminal model

Translating this model using the modular approach resulted in the following submodels:

- A - Ships unloading low sulfur coal and loading high sulfur coal
- B - Barges unloading high sulfur coal and loading low sulfur coal
- C - Trains unloading high sulfur coal and loading low sulfur coal

The entities in the model are ships, barges, trains, empty barges and empty trains. The entity "scoop" was defined as the amount of coal that is moved at a time. A ProcessModel scoop entity was developed that is displayed and moved on the screen during coal unloading and loading. The resources are ship berths, barge berths, train slots, ship cranes, coal car flippers, tugs and four types of conveyors.

Simulation Results

The simulation results indicated that the coal terminal can unload 21million tons and load 19 million tons annually. Because of the nearly 100% utilization of several of the resources, it appears that the goal of 30 million tons annually may not be possible without an equipment upgrade.

MODEL 2 - IMPACT OF CONTINUOUS IMPROVEMENTS ON COAL TERMINAL

The systems and equipment at the McDuffie Terminal at the Alabama State Docks have evolved over the years resulting in inefficiencies in the operations and processes. The condition of equipment and processes, along with customer requirements for increased coal volume led management to find opportunities to improve operational efficiency, system productivity and coal throughput. The management team at the port became aware of the principles of lean manufacturing and continuous improvement through a series of meetings and educational programs and agreed to try the approach at the McDuffie Terminal [5].

The main focus of a continuous improvement culture is to identify and eliminate inefficiencies, termed waste, in a process and create value in the eyes of the customer [6, 7]. The wastes can be categorized into overproduction, inventory, defects, motion, transportation, waiting, over processing and underutilizing people [8, 9]. Many of the operations at the McDuffie Terminal would not typically be considered value added. Examples of these non-value added activities are equipment setup and breakdown, unevenness in scheduling, handling and movement of coal throughout the terminal and coal storage. Ideally coal would arrive at the coal terminal and be immediately dispensed to another transportation mode for delivery to the customer, much like cross docking at a truck terminal. However, economic conditions within the coal industry make the storage of strategic inventory at McDuffie Coal Terminal a desirable market smoothing mechanism.

Eight kaizen process improvement events [6, 7, 8, 9] were conducted at the coal terminal between 2005-2006 with the goal of improving operations efficiency and increasing productivity, throughput and velocity. The results of the kaizens identified barge loading/unloading and ship unloading as primary areas for improvement.

Model

The modular approach was used to evaluate the impact of the continuous improvement events on the operations of the McDuffie Terminal [3]. Interestingly the ProcessModel was almost identical to Model 1 described in the previous section. The only modifications were the logic in several of the ProcessModel activity blocks and some of the data input [10]. Consequently, the model was operational in a very short time.

Simulation Results

The Alabama State Docks implemented most of the recommendations from the eight kaizens at minimum costs and with very little capital expenditures. For example, several of the recommendations were to develop standard operating procedures, list of maintenance activities, shift change procedures, daily maintenance checklists and critical spare parts lists. These recommendations resulted in a reduction in the time for unloading and loading barges and an increase in the throughput tonnage per day. The simulation model, not only verified that the kaizen recommendations were achievable, but also provided additional insight in the operations of the terminal, credibility to the kaizen events and overall comfort to management during the implementation of the recommendations. As a result of the kaizen events the port realized a significant increase in throughput capacity and a corresponding reduction in operating costs.

MODEL 3 - EXPANSION OF CONTAINER TERMINAL

The Alabama State Docks is currently enhancing container and intermodal operations in Mobile, Alabama through the construction of a new container terminal. The shipping terminal will include 92 acres with 2,000 feet of berthing space dredged to a depth of 45 feet for two berths. A grade-separated roadway will connect the container terminal with an intermodal terminal and value added warehousing and distribution area.

The new container terminal will be capable of handling 250,000 to 300,000 TEU's (Twenty-foot Equivalent Unit) annually. The Alabama State Docks was interested in validating the design capacities of the container terminal. Of special interest were the utilization of the berths, cranes and stackers and the maximum container throughput of the terminal. The modular approach was used to validate capacity and resource utilizations.

Model

Figure 4 depicts the model of the container terminal at the Alabama State Docks [11]. Containers arriving on ships depart on trains and trucks. Containers arriving on trains and truck depart on ships. Translating the model into the modular approach resulted in the following submodels:

- A - Ships unloading and loading containers
- B - Trains unloading and loading containers
- C - Trucks unloading and loading containers
- D - Movement of containers from ship dock to container yard
- E - Movement of containers from container yard to ship dock
- F - Movement of containers from train payment to container yard
- G - Movement of containers from container yard to train payment

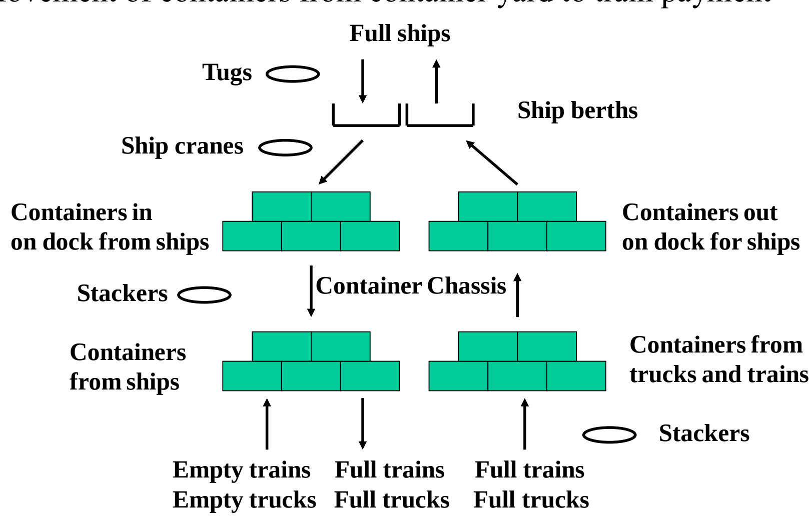

FIGURE 4 Container terminal model

Entities are ships, trains, trucks, empty trains, empty trucks and trucks with empty containers. A ProcessModel container entity was developed that is displayed and moved on the screen during any container movement such as unloading and loading. There are also four move order entities that trigger the movement of containers between ships, trains and trucks and the container yard. The resources are ship berths, train slots, truck slots, tugs, ship cranes, stackers and chassis. The model does not address stacking and sorting of containers in the terminal. There is no unique identification of containers.

Figure 5 contains the simplified ProcessModels for submodels A, D, and E. In submodel A containers are unloaded and placed on the dock. The global variable Containers_on_dock_unloaded is incremented by one as each container is unloaded. After all the containers have been unloaded other containers are loaded back onto the ship. Containers are loaded as long as global variable Containers_on_dock_load is greater or equal to one. After a container has been loaded the global variable Containers_on_dock_load is decremented by one.

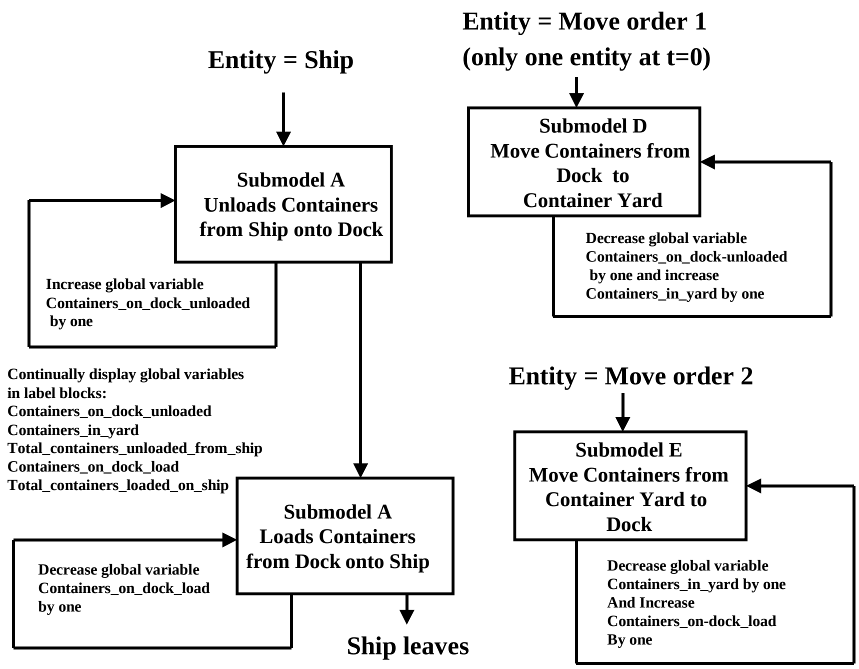

FIGURE 5 Simplified ProcessModel for Submodels A, D and E

Submodel D continually checks to see if global variable Containers_on_dock is greater or equal to one. If so, a container is moved from the dock to the container yard. The global variable Containers_on_dock_unloaded is then decremented by one and the variable Containers_in_yard incremented by one.

Submodel E continually checks to see if global variable Containers_in_yard is greater or equal to one. If so, a container is moved from the container yard to the dock. The global variable Containers_in_yard is decremented by one and the variable Containers_on_dock_load is incremented by one.

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

TABLE 1 Experimental design

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

Simulation Results

A goal of 325,000 containers annually is feasible with the proposed design parameters. Run12 in Table 1 exceeded the goal and Run7 came close to the goal. To achieve this design goal the time between arrivals of ships must drop from three days for Run1 to one day and the time between arrivals of trains must drop from three days for Run1 to twelve hours.

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

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

MODEL 4 - IMPACT OF INCREASED SECURITY INSPECTIONS ON CONTAINER TERMINAL

Increased security is having a significant impact on the operations of ports resulting in longer times that ships, trains and trucks are at container terminals. Ports are wrestling with various inspection procedures and installing equipment to minimize the container inspection times.

This model determined the impact of various container inspection protocols on the operation of a container terminal at the Alabama State Docks in Mobile, Alabama. The three inspection protocols are A) no inspection, B) container sampling with unloading and inspection coupled and C) inspection after unloading or decoupling inspection from unloading [12].

Model

The modular approach was used to evaluate the impact of each inspection protocol on container throughput [12]. Interestingly the ProcessModel was almost identical to Model 3 described in the previous section. The only modifications were the logic in several ProcessModel activity blocks and some of the data input. Consequently, the model was operational in a very short time. Table 2 presents the experimental design. Protocol A is the Baseline Run1 with no container inspection. An inspection rate of 100% is used in Run2, 80% in Run3 and 60% in Run4. In Protocol C (Run5) the inspection is decoupled from container unloading and all containers are inspected independently of unloading from the ship.

TABLE 2 Experimental design

Run	Description
Run1	Protocol A - no container inspection (Baseline Run)
Run2	Protocol B - 100% inspection of incoming containers
Run3	Protocol B - 80% inspection of incoming containers
Run4	Protocol B - 60% inspection of incoming containers
Run5	Protocol C – Container inspection independent of unloading

Simulation Results

The simulation results indicated that any sampling plan using Protocol B had an impact on entity throughput. This is because of the rule that the container must be inspected before another container is unloaded. However, 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. Any inspection plan for containers that includes inspection as a part of the unloading operation, such as that described in Protocol B, increased the times for entities at the terminal. For example, 100% inspection of all incoming containers increased the time a ship was at the terminal by 260%, a train by 477% and a truck by 96%. A 60% sampling plan of incoming containers increased the time a ship was at the terminal by 38%, a train by 44% and a truck by 20%

Decoupling the container inspection from the unloading of the container minimized the impact of the inspection. The inspection Protocol C for Run5 resulted in entity times identical to the Baseline Run with no inspection. The time a ship was at the terminal was 2,007 minutes for Run5 as compared to 2,013 minutes for the Baseline Run. The time a train was at the terminal was 695 minutes as compared to 684 for the Baseline Run. The time a truck was at the terminal was 33 minutes as compared to 26 minutes for Baseline Run. It can be assumed that the decoupled inspection process might require similar resources to the in-process inspections described in Protocol B.

MODEL 5 - OPERATIONS OF INTERMODAL CENTER

The International Intermodal Center 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. The Intermodal Center is served by Norfolk Southern Railroad and operates its own Class 3 Rail Service to move container car pulls to and from the main line [13].

The Intermodal Center had an interest in 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 to be answered by the simulation model were: 1) can container throughput satisfy anticipated demand, and 2) are resources sufficient to support anticipated growth in demand?

Model

Figure 6 is the model of the intermodal terminal center at the Huntsville International Center [13]. Containers arriving on airplanes depart on trucks. Containers arriving on trains depart on airplanes and trucks. Containers arriving on truck depart on airplanes and trains. Translating this model into the modular approach resulted in the following submodels:

- A - Planes unloading and loading of containers
- B - Trains unloading and loading of containers
- C - Trucks unloading and loading of containers
- D - Movement of containers from plane dock to container yard
- E - Movement of containers from container yard to plane dock
- F - Movement of containers from train dock to container yard
- G - Movement of containers from container yard to train dock

Entities are planes, trains, trucks, empty trucks, empty trains and trucks with empty containers. There are also four move order entities. The resources are plane terminals, train slots, truck slots, gantry cranes, plane forklifts, stackers and chassis.

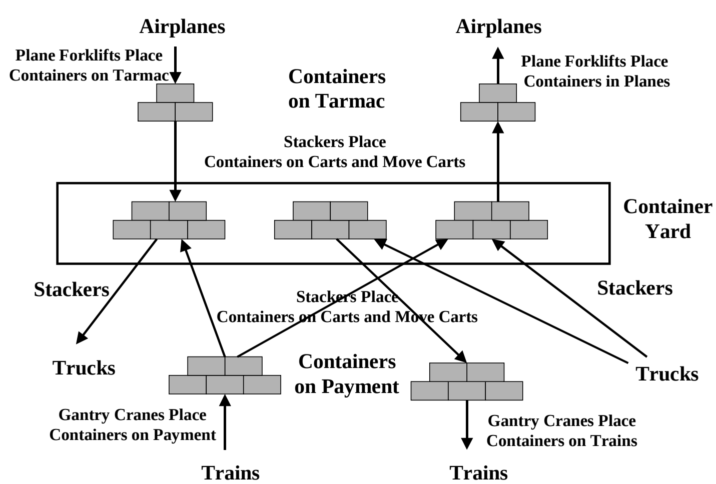

FIGURE 6 Intermodal center model

The experimental design is given in Table 3. 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 Run11. Runs 12-15 evaluated Run11 with fewer resources by continuing decreasing the number of plane and train terminals, truck slots, plane and train lifts, stackers and chassis.

TABLE 3 Experimental design

Run	Description
Baseline Run1	Current intermodal center operations
Runs 2-10	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
Runs 12-15	Multiple runs reducing the number of resources in Run11

Simulation Results

The reduction in truck slots from twenty for the Baseline Run1 to 12 for Run10 indicates that only twelve 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 significantly because of higher waiting times for either a resource or a container. Future research may be warranted in using overall equipment effectiveness instead of equipment utilization as a measure.

Another run which was not of the experimental design, Run16, indicated that considerably more container traffic is possible, with the existing resources, from the Baseline Run1. Run16 indicated that these resources can process 68,118 lifts annually. This is a 51% increase over the projected 2007 container traffic of 45,000 lifts.

SUMMARY OF RESULTS

Table 4 presents a comparison of the five models developed using the modular approach. The first model developed was the coal model, followed by the container model and finally the intermodal model. The impact of a number of continuous improvement events was also added to the coal model helping validate the impact of continuous improvement activities by port personnel (Model 2). The impact of increased security inspection of containers was added to the container model allowing stakeholders to better understand the effects of supporting different inspection protocols (Model 4).

The model development times were 48 hours for the coal model, 32 hours for the container model, 16 hours for the intermodal model, 16 hours for Model 3 and 16 hours for Model 4. The intermodal model (Model 5) was the most complex model, especially in terms of the logic; however, this model required the least development time, showing a learning effect and the use of previously defined models.

TABLE 4 Comparison of various models

	Coal Model 1	Container Model 3	Intermodal Model 5	Coal Model 2 – Continuous Improvements	Container Model 4 – Security Inspections
Submodels	3	7	7	3	7
Entities	5	7	9	5	7
Blocks	43	50	55	49	55
Attributes and Global Variables	10	23	28	10	23
Logic Statements	110	99	178	120	109
Development Time (hours)	48	32	16	16	16
V&V Time (hours)	16	12	12	8	8
Data Collection Time	12	8	8	4	4

CONCLUSIONS

Regarding the use of simulation as an inexpensive tool providing answers to questions at the Alabama State Docks and the Huntsville International Intermodal Center, the following conclusions are made:

- The modular approach provides an excellent template in the development of port and terminal simulation models. This framework greatly reduced model development time, debugging, and verification & validation. Each submodel can be debugged and verified separately, thus reducing development time. The submodels for the five applications were very similar. Consequently, the ProcessModels for the submodels were similar with the exception of the branching logic.

- The time to develop the models varied between 16 and 48 hours and is considerably less than traditional model developments. Likewise, the verification & validation was between 8 and 16 hours. More importantly, data collection was between 4 and 12 hours with the use of the triangular distribution, the primary reason for these low data collection times.

• The use of the global variables was also similar for all five applications. As a result, the use of the ProcessModel Label Blocks function was similar.

• Modifications to a model were simplified because of the modular framework. Changes made to a submodel could be easily debugged without having to worry about the other submodels.

• Data collection was done by interviewing the personnel at the Alabama State Docks and the Huntsville Intermodal Center. It is rather easy to ask knowledgeable personnel the most frequent values, the smallest values and the largest values to obtain the parameters for the triangular distributions.

In conclusion the modular approach has been demonstrated as an effective tool for rapidly developing simulation models that can analyze and evaluate existing port planning and operations, changes in operations and capital expansions.

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