APPLICATION OF SIMULATION TO IMPROVE VOLUME THROUGH A SEAPORT COAL TERMINAL

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ABSTRACT. The Alabama State Port Authority wants to increase the volume of coal moving through the McDuffie Island Coal Terminal. A perceived barrier to an increase in capacity is the number of tugboats for moving barges throughout the terminal. This paper presents a simulation model for evaluating the various tugboat alternatives for improving the velocity of coal through the terminal. Additionally, the simulation will examine other potential constraints to the flow of coal and identify opportunities for productivity improvement. Included in this paper are a description of the coal terminal, a description of the conceptual framework of the simulation model, the experimental design, unique modeling features and the analysis of the results. This research was sponsored by the U.S. Department of Transportation, Federal Transit Administration, Project No. AL-26-7262-00.

INTRODUCTION

The McDuffie Island Coal Terminal was established in 1976 as an export facility at the Alabama State Docks in Mobile, Alabama and consists of 556 acres. It 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 electrical power generation plants. Total tonnage through the terminal for FY05 was 15,500,000 tons. Total ground capacity (inventory) is 2,300,000 tons. Theoretical annual throughput capacity is currently 20,000,000 tons. Figures 1 and 2 present an orientation to the McDuffie Island Coal Terminal.

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Figure 1. View of the McDuffie Island Coal Terminal

Figure 2. Operations at the McDuffie Island Coal Terminal

RESEARCH OBJECTIVE

Customers of McDuffie Island Coal Terminal have expressed the need for the coal terminal operations to increase the volume through the terminal to 30,000,000 tons annually. The systems and equipment at the coal terminal have evolved over the years resulting in inefficiencies in the operations and processes. The state of equipment and processes, along with customers demanding increased volume led management to seek opportunities to improve efficiency, productivity and throughput. One area of concern to increasing the throughput is the number of various tugboats used to support the operations at the terminal. Consequently, this project focuses on the number of tugboats available and the use of these tugboats to achieve the desired increase in throughput.

PREVIOUS RESEARCH

An earlier, comprehensive simulation model of the McDuffie Island Coal Terminal was developed to evaluate various continuous improvements to the handling of coal at the terminal by Harris, et al. (2007). This earlier model was developed using the discrete event simulation package ProcessModel. The goal of the study was to determine the maximum capacity of the terminal after the implementation of a number of kaizen activities (process improvements) resulting from the application of lean manufacturing principles to improving operational processes and eliminating waste at the terminal.

Sanchez, et.al. (2007) developed a port simulation model for the discharge and the delivery of coal at the Lazaro Cardenas Port in Mexico. The model includes six terminals to handle oil, coal, grains and containers. The model has been used to determine the optimum number and size of piers to handle coal. Bruzzone and Giribone (1995) developed a methodology based on simulation and virtual reality in a web environment as a decision support system for port operations. Included in the methodology is a bulk terminal simulation element.

Dragovic, et al. (2005) evaluated alternative strategies for ship-berth performance using simulation models. The results indicated that simulation of these activities is a very effective method for examination of the impact of establishing priority for certain classes of ships. Jula, et al. (2006) utilized simulation to study potential methodologies to reduce congestion at the LA/LB port due to empty containers. The authors found that the simulations indicate significant cost reductions could be achieved by understanding the appropriate strategy.

Ferretti and Bruzzone (1999) developed a simulator to study coal terminals. The simulator has been written is Visual C++ and includes a graphical interface for evaluating plant dynamics and viewing results.

MODEL CONCEPTUAL FRAMEWORK

Figure 3 depicts the conceptual framework of the tugboat model. Two coal piles, a low sulfur coal pile and a high sulfur coal pile are used in the model of the coal terminal. High sulfur coal arrives on barges and trains and leaves on ships. Low sulfur coal arrives on ships and leaves on barges and trains. Orders for low sulfur coal are presented as a request for six barges with a capacity of 1,500 tons each. Upon the receipt of a coal, order barge tugboats move six empty barges from the barge holding area to the barge loading area.

The model employs three types of tugboats: ship tugboats, barge tugboats and customer tugboats. Ship tugboats move incoming ships from the harbor to ship berths for unloading low sulfur coal. After unloading their low sulfur coal, and then loading with high sulfur coal, ship tugboats move the sea vessel back into the harbor.

The model also includes customer tugboats for moving outgoing barge orders (six-packs) to the customer site and for moving incoming barges (six-packs) of high sulfur coal into the barge holding area. Full barges arrive in a group of six barges, called a six-pack, with each barge holding 1,500 tons of high sulfur coal. The full barges are relocated to a holding area by a customer tugboat.

The barge tugboats then move the full barges to the barge berths for unloading. After unloading the high sulfur coal, the barge tugboats move the empty barges to the barge holding area.

The model has several barge holding areas: storage of empty barges, incoming full barges of high sulfur coal and outgoing full barges of low sulfur coal. Only when an order for low sulfur coal is received will an empty barge be moved into location for filling. Full barges are only moved for unloading when a barge birth is available at the unloading operation.

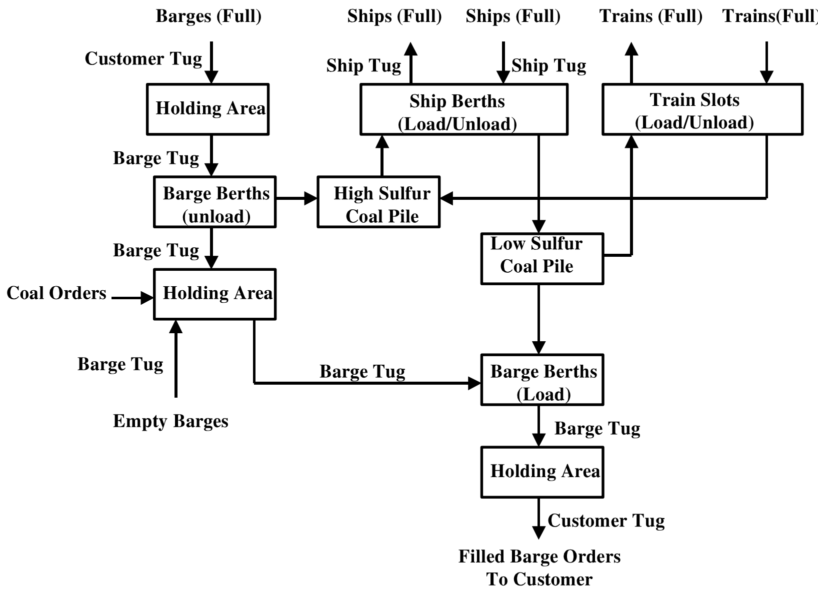

Figure 3. Conceptual framework for model

The model employs the following resources:

- Ship berths
- Ship tugboats
- Barge berths for unloading
- Barge berths for loading
- Barge tugboats
- Trains slots for unloading
- Train slots for loading
- Customer tugboats for moving coal to and from customers

The model does not include logic for the reclaimers and the ship cranes. These resources were included in the model by Harris, et al. (2007a). To simplify the model, coal is unloaded and loaded in bulk quantities. For example, a ship is unloaded in 15,000-ton quantities. In comparison, the Harris et al. (2007a) model unloads and loads in scoops where a scoop may be from 25-50 tons. This simplifying assumption is not a critical issue for this model since the objective is to evaluate tugboat utilization rather than the detailed movement of coal at the individual scoop level. An overview of the model is given in Figure 4. The model was developed in ProcessModel (1999) and consists of the following submodels:

- Coal orders of six barges for low sulfur coal (entity = coal order)
- Ships unloading low sulfur coal and loading high sulfur coal (entity = ship)
- Barges unloading (six barges) high sulfur coal (entity = barge_six_pack)
- Trains unloading high sulfur coal and loading low sulfur coal (entity = coal_train)
- Empty barge arrival (six barges) (entity = barges_empty)

These submodels run independently of one another, each with a different entity. Data are passed between the submodels by a number of global variables. In addition, a number of attributes are assigned to the entities. These variables and attributes control entity movement, branching and activity operations.

The simulation utilizes several Labels, a key feature of the ProcessModel software that allows the continuous display of selected global variables. This feature aides the modeler in verifying the model functions.

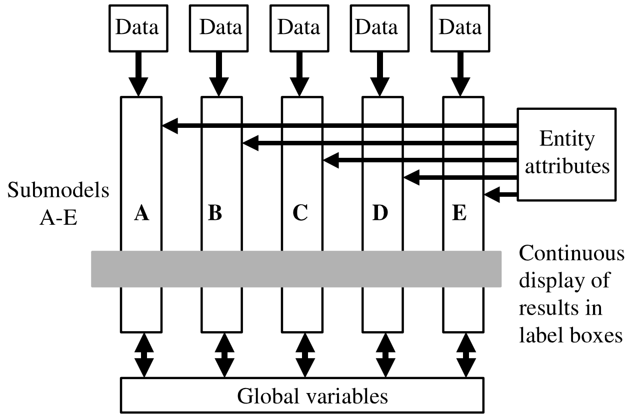

Figure 4. Overview of ProcessModel

Figure 5 presents the actual simulation as seen in ProcessModel for the unloading and loading of ships. The ProcessModel logic for the barges and coal trains is similar. The comments next to each block describe the logic in the action section of that block. The eight gray boxes are the label boxes that continuously display the content of selected global variables.

VERIFICATION AND VALIDATION

Model verification consists of determining if the model is correctly represented in the simulation code. Model validation consists of determining if the model is an accurate representation of the real world system.

As previously stated, ProcessModel has a Label block that displays data from the global variables during the simulation and are used in the model verification. By slowing down the simulation, it is possible to observe these values as entities move through the simulation. For example, the high sulfur coal unloaded minus the high sulfur coal loaded should equal the current high sulfur coal pile inventory. Likewise, a similar calculation can be made for the low sulfur coal. These calculations can be made at any time during the simulation by pausing the simulation and observing the values in the ProcessModel Label boxes.

Model verification consisted of running the model for 720 hours (or 30 days) with the following results in the label boxes at time 720 hours, the end of the simulation:

Low sulfur coal pile	5315 tons
High sulfur coal pile	69,960 tons
Low sulfur coal in from ship	643,815 tons
High sulfur coal in from barge	539,895 tons
High sulfur coal in from train	130,065 tons
High sulfur coal out on ship	600,000 tons
Low sulfur coal out on barge	538,500 tons
Low sulfur coal out on train	100,000 tons

The total low sulfur coal arriving minus total low sulfur coal out should equal current low sulfur coal pile. Or 643,815 – (538,500+100,000) = 5,315 tons in the current low sulfur coal pile. Likewise for the high sulfur coal (539,895+100,000) – 600,000 = 69,960 tons in the current high sulfur coal pile. Model validation was not possible since much of the data was based on implementing the continuous improvements stated in Harris, et al. (2007a). However, a team of individuals familiar with the operations of the existing terminal was assembled to visually observe the operations of the terminal during the simulation. The

ProcessModel was stopped throughout the simulation and the values observed such as queues, number of empty barges, unloaded and loaded tonnage, and resource utilizations. The subject matter experts agreed that the model was accurately replicating the operations of the coal terminal.

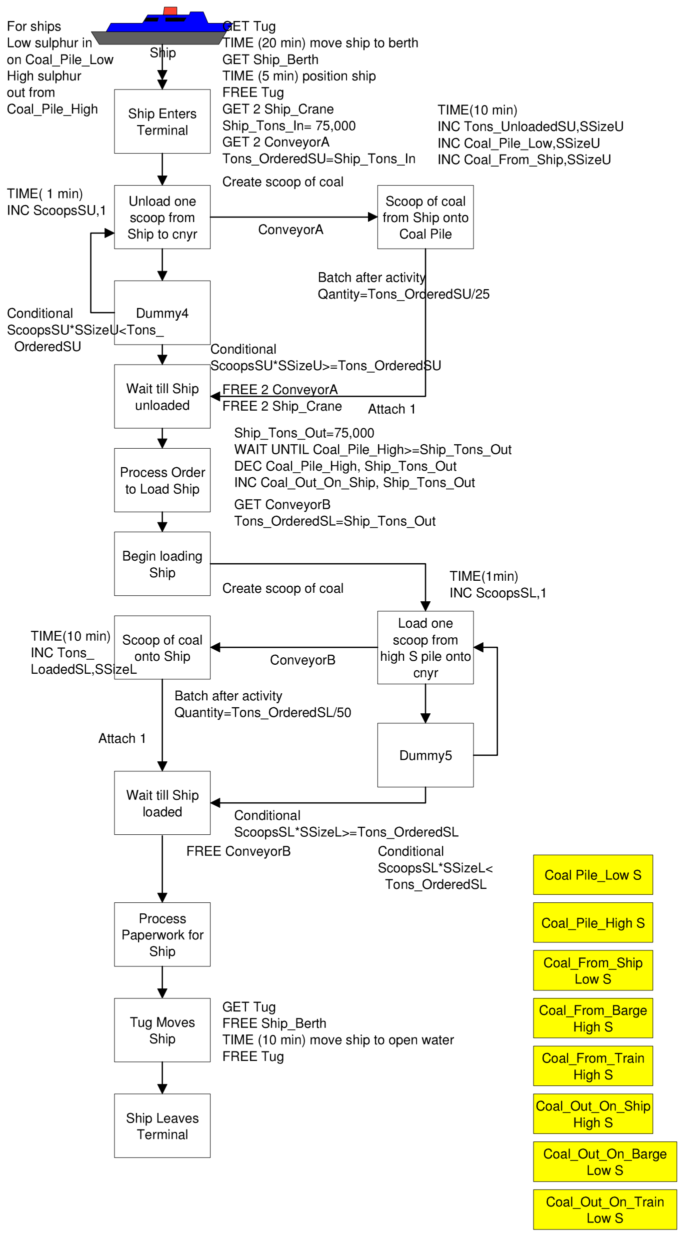

Figure 5. Screen Shot of the Unloading and Loading of Ships in ProcessModel

EXPERIMENTAL DESIGN

Since the primary model objective was to evaluate tugboat utilization, several tugboat protocols are defined. The baseline model contained the tugboat protocol below (Protocol A):

Ships	**Full Barges**
Get ship tugboat and move ship to berth	Get barge berth for unloading
Get ship berth and position ship in berth	Get Barge tugboat and move to berth
Free ship tugboat	Free barge tugboat
Unload and load ship	Unload barge
Free ship tugboat	Free barge berth for unloading

Coal Orders
Get barge berth for loading
Get barge tugboat and move barge to berth
Free barge tugboat
Load barge
Free barge berth for loading

The resources for the baseline model were:

- 1 ship tugboat
- 2 barge tugboats
- 10 customer tugboats
- 3 ship berths
- 2 barge berths for unloading
- 2 barge berths for loading
- 2 train slots for unloading
- 1 train slot for loading

Arrival and service times and coal capacities for the baseline model were:

- Time between arrivals for ships 2,160 minutes; 360 minutes for six full barges; 480 minutes for coal order of six barges; 1,440 minutes for trains; 2,880 minutes for six empty barges
- Coal capacity of ships incoming 75,000 tons and outgoing 75,000 tons
- Coal capacity of trains incoming 10,000 tons and outgoing 10,000 tons
- Coal capacity of barge incoming 1,500 tons (9,000 tons for group of six barges)
- Coal capacity of barge outgoing 1,500 tons (9,000 tons for six barges in a coal order)
- 3,000 minutes to unload ship, 2,100 minutes to load ship
- 100 minutes to unload one barge (600 minutes for a six-pack)
- 110 minutes to load one barge (660 minutes for a six-pack)
- 600 minutes to unload train, 200 minutes to load train
- 20 minutes for movement times of barges between holding areas and barge berths
- 20 minutes to move ship to berth and from berth
- 20 minutes for customer tugboat to move order (six barges) to customer (selected to reduce simulation time)

These times are based upon the implementation of the continuous improvements that have been performed at the terminal and validated by Harris, et.al. (2007). Actual times taken at the terminal for many of the activities are longer since all improvements have not been fully implemented or sustained. Again, to simplify the model all the time distributions were reduced to only the mean values.

The simulation started empty and idle, with no ships, barges or trains initially at the terminal; 25 empty barges were in the holding area; and both coal piles had 25,000 tons each. The experimental design for the remaining runs is shown in Table 1. All other data remained the same as the Baseline Run with the exception of the tugboat protocol.

The tugboat protocol (Protocol B) for Runs 1-5 was:

Ships (same as Protocol A)
Get ship tugboat and move ship to berth
Get ship berth and position ship in berth
Free ship tugboat
Unload and load ship
Free ship tugboat

Full Barges
Get barge tugboat and move barge to berth
Free barge tugboat
Get barge berth for unloading
Unload barge
Free barge berth for unloading

Coal Orders
Get barge tugboat and move barge to berth
Free barge tugboat
Get barge berth for loading
Load barge
Free barge berth for loading

Table 1. Experimental Design

Run	Ship Tugboats	Barge Tugboats
Baseline (Protocol A)	1	2
Runs 1-5 (Protocol B)		
Run1	1	2
Run2	2	2
Run3	3	2
Run4	2	3
Run5	3	3

ANALYSIS OF SIMULATION RESULTS

The simulation model was run for six months or 4,320 hours (24 hours/day). Figure 6 gives the utilization of the ship and barge tugboats for each run. For the Baseline Run the ship tugboat utilization for one tugboat was 94% and the average barge tugboat utilization for two tugboats was 100%. The primary reason for these very high utilizations can be attributed to the Protocol A rules for seizing and releasing tugboats.

The ship and barge tugboats utilizations dropped significantly with the Protocol B rules. For example, for Run1 the ship tugboat utilization was 75% and the average barge tugboat utilization was 58%. The number of tugboats was increased for Runs 2-5. The average ship tugboat utilization varied from 75% for Run1 to 65% for Run5. The average barge tugboat utilization varied from 58% for Run1 to 38% for Run5.

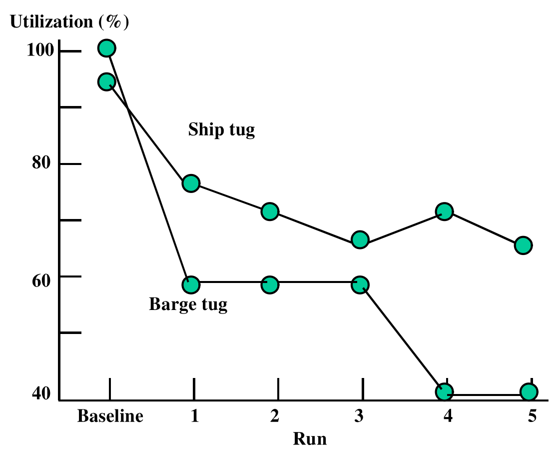

Figure 6. Ship and barge tugboat utilizations

Table 2 gives the number of entities through the system and the average time the entities were in the terminal after running the model for 4,320 hours. The average times dropped significantly from the Baseline Run to Run1. Note that the number of ship and barge tugboats remained constant at one ship tugboat and two barge tugboats for both the Baseline Run and

Run1. Since the utilization of the barges was near 100% for the Baseline Run and considerably less for Run1, it is obvious that the average entity times should drop accordingly.

The number of tugboats was increased for Runs 2-5. However, the number of trains unloaded and loaded, full barges unloaded, and completed coal orders did not increase (See Table 2). In addition, the average time each of these entities was in the terminal remained constant. There was a slight reduction in the average time a ship and a full barge was in the terminal.

Table 2. Entity Throughput and Time in Terminal

Run	**Ship**		**Coal Orders**		**Full Barges**		**Coal Trains**	
	No.	**Time (min)**	**No.**	**Time (min)**	**No.**	**Time (min)**	**No.**	**Time (min)**
Baseline	25	99,692	91	64,613	180	3,964	104	49,495
Run1	108	15,951	540	388	4,318	262	180	801
Run2	109	14,401	540	388	4,318	262	180	801
Run3	110	13,078	540	388	4,318	262	180	801
Run4	109	14,388	540	388	4,318	246	180	801
Run5	110	13,065	540	387	4,318	246	180	801

The value added time for a coal train is 600 plus 200, or 800 minutes. Since the average time in the terminal for a coal train was 801 minutes, there were no delays in unloading and loading a coal train. The value added to unload a full barge is around 300 minutes (6 x 100 minutes / 2). Again, there were no delays for unloading full barges. The value added time for a coal order is 420 minutes (6 x 100 minutes / capacity of 2) + (6 x 40 minutes / capacity of 2). The value added time for unloading and loading a ship is 5,040 minutes (20 + 3,000 + 2,000 + 20). Table 2 shows ship entity throughput of 15,951 minutes for Run1 indicating a delay of over 10,000 minutes.

Table 3 gives the tonnage loaded and unloaded after running the model for 4,320 hours. The coal throughput was very low for the Baseline Run as compared to Runs 1-5. The only modification to the model between the Baseline and Run1 was the protocol for the usage of the ship and barge tugboats.

Table 3. Tonnage Loaded and Unloaded

Run	**High Sulfur**		**Low Sulfur**		**Coal Pile**	
	In (tons)	**Out (tons)**	**In (tons)**	**Out (tons)**	**High Sulfur (tons)**	**Low Sulfur (tons)**
Baseline	2,100,000	2,000,000	2,200,000	1,900,000	4,000	500
Run1	8,300,000	8,200,000	8,400,000	6,700,000	7,000	268,000
Run2	8,300,000	8,200,000	8,400,000	6,700,000	7,000	268,000
Run3	8,300,000	8,200,000	8,400,000	6,700,000	7,000	268,000
Run4	8,300,000	8,200,000	8,400,000	6,700,000	10,000	268,000
Run5	8,300,000	8,200,000	8,400,000	6,700,000	10,000	268,000

The annual throughput can be estimated by adding the 16,400,000 tons of high sulfur loaded to the 13,400,000 tons of low sulfur loaded to get a total of 29,800,000 tons (operating 24 hours/day). This annual capacity is close to the goal of the State Docks.

ANALYSIS OF RUN3

Run3, with 3 ship tugboats and 2 barge tugboats, had one of the lowest ship processing times of 13,098 minutes as compared to 15,951 minutes for Run1. Therefore, in this section the authors provide a more detailed analysis of the results for Run3. First, the empty barge submodel was deactivated. There were already 1103 empty barges in the holding area at the end of the simulation. This was due to the barges being unloaded at a faster rate than needed to fill the coal orders. The time between arrivals for full barges was 360 minutes while the time between arrivals for coal orders was 480 minutes. Several other results for Run3 are:

Utilization of resources		**Utilization of selected activities**	
Barge berth load (2)	68%	Load barge	68%
Barge berth unload (2)	83%	Unload barge	83%
Ship berth (3)	95%	Load ship coal	52%
Train slot load (1)	13%	Unload ship coal	43%
Train slot unload (2)	20%	Load train	13%
		Unload train	20%

These results suggest that it may be possible to increase coal throughput at the terminal due to the relative low utilizations of the ship and train resources and activities. An additional model run, Run3A, was made with the modifications to Run3 shown in Table 4.

Table 4. Modification to Run3

Time between arrivals	Run3	Run3A
Ships of low sulfur coal	2,160 min	1,680 min
Barges of high sulfur coal	360 min	240 min
Trains of high sulfur coal	1,440 min	1,200 min
Coal order	480 min	420 min

Table 5 compares the results of Run3A with Run3. The results of Run3A reveal the interactions and constraints between the various submodels. Making a change in one submodel may or may not have a significant impact on another submodel due to the situation where each model was individually developed and then linked together, thus, the desired results may not be achieved.

Note the very large increase in the time at the terminal for the unloading of barges. The utilization of the resources Barge_Berth_Unload was already 83% for Run3 and reached 99% for Run3A. As a result, a decrease in the time between arrivals only increased the wait until a barge could be unloaded. Likewise, the utilization of the resources Ship_Berth was 99% and the average time to unload and load a ship increased to 20,444 minutes.

Tonnage loaded at the terminal increased to 17,600,000 tons for six months with 563,500 tons remaining in the low sulfur coal pile. The high sulfur coal pile remained relatively small at 13,000 tons.

Table 5. Comparison of Results of Run3A with Run3

	Run3	Run3A
Number of		
Coal orders	540	617
Ships	110	132
Barges	4,318	5,180
Trains	180	216
Time at terminal		
Coal orders	388 min	388 min
Ships	13,078 min	20,444 min
Barges	4,318 min	26,141 min
Trains	801 min	801 min
Utilization		
Ship tugboats	65%	84%
Barge tugboats	58%	68%
Ship berths	95%	99%
Barge berths unload	83%	99%
Barge berths loaded	68%	78%
Train slots unload	20%	25%
Train slots loaded	13%	16%
High sulfur unloaded	8,300,000 tons	9,900,000 tons
Low sulfur unloaded	8,400,000 tons	10,000,000 tons
High sulfur loaded	8,200,000 tons	9,900,000 tons
Low sulfur loaded	6,700,000 tons	7,700,000 tons
High sulfur pile	7,000 tons	13,000 tons
Low sulfur pile	268,000 tons	563,500 tons

MODIFICATION TO SHIP PROTOCOL (RUN3B)

After further analysis of the protocols, it appears that a change to the ship protocol for Run3A could impact tugboat utilization and consequently throughput. Run3B consisted of changing the ship protocol for Run3 to:

Ships
Get ship berth
Get ship tugboat, move ship to berth and position ship in berth
Free ship tugboat
Unload and load ship
Free ship tugboat

This protocol first makes certain there is an available ship berth before calling for a ship tugboat. On the other hand, the protocol for Run3A was to first get the ship tugboat before checking if there was an available ship berth. In Run3A, the ship tugboat may have to wait with the ship until a ship berth becomes available that results in high ship tugboat utilization. In addition, the number of tugboats was reduced to one ship tugboat and two barge tugboats, the same as Run1. All other data remained the same as Run3.

Surprisingly the results were the same as for Run3A with the exception of tugboat utilization. A comparison of tugboat utilizations is presented in Table 6. Notice the large reduction in the utilization of the ship tugboats. The ship tugboat utilization went from 84% with three tugboats for Run3A to only 2% with one tugboat for Run3B.

Table 6. Comparison of tugboat utilizations for Run3A and Run3B

	Run3A	Run2B
Ship tugboats	84%	2%
Barge tugboats	68%	68%
Ship berths	99%	99%
Barge berth unload	99%	99%
Barge berth load	78%	78%
Train slots unload	25%	25%
Train slots load	16%	16%

UNIQUE MODELING FEATURES

The coal terminal simulation model has a number of interesting features. Several of these are 1) modeling a continuous system using discrete event simulation, 2) concept of the coal scoop and 3) model modularity. Each feature is discussed in the following paragraphs.

Continuous Simulation

The simulation clock in discrete event simulations only moves entities when an event occurs such as the completion of an activity. On the other hand the simulation clock in continuous simulations moves at some fixed delta time. The movement of coal is generally continuous and on conveyors. Even the unloading and loading is via conveyors and can be considered continuous.

PocessModel is a discrete event simulator. Therefore, to simulate the continuous movement of the coal an entity called a scoop of coal was created to move the coal. By placing the scoops of coal on the conveyor in equal time increments the simulation moves the scoops in uniform increments simulating the continuous movement of the coal through the system. As described in the next section the animation on the computer screen appears that the coal is continuously moving on the conveyor when in reality the coal is moving in scoops. The scoops are equivalent to discrete event entities and can be easily tracked and statistics collected during the simulation.

Scoop Concept

Figure 7 is the conceptual framework for loading coal from the coal pile onto a ship. A large piece of equipment called a reclaimer is central to the coal terminal operation. The reclaimer functions as the engine for the conveyor system used to take coal to and deliver coal from the coal inventory piles. The reclaimer shown in Figure 2 has a large wheel with scoops. The wheel spins and collects coal from the pile and deposits it onto a conveyor that delivers the coal to a shipment location.

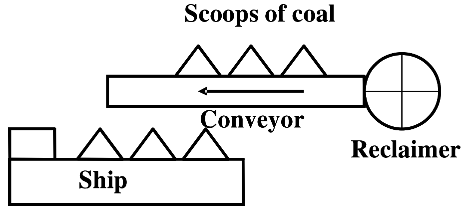

Figure 7. Conceptual framework for loading coal from coal pile onto a ship

An explanation of the operation of the scoop concept is described for the loading of coal onto ship follows. At activity named Load_One_Scoop_From_High_S_Pile_Onto_Cnyr a scoop of coal is picked up by the reclaimer and placed on ConveyorB. An entity, Scoop_Coal, is created and routed to activity Scoop_Of_Coal_Onto_Ship. At the same time, the parent entity loops until all the ordered coal has been placed on ConveyorB. During each loop another entity, Scoop_Coal, is created and routed to activity Scoop_Of_Coal_Onto_Ship. A conditional test ScoopsSL*50<Tons_OrderedSL controls the loop. Once the conditional test has been met (ScoopsSL*50>=Tons_OrderedSL), all the necessary scoops have been loaded onto ConveyorB and the parent entity goes to Wait_Till_Ship_Loaded.

The activity Scoop_Of_Coal_Onto_Ship has a capacity of 5000 entities, representing the coal capacity of the conveyor. The activity time represents the time for a Scoop_Coal to move from the coal pile to the ship. The entities are then batched with the batch quantity equal to the total tons (i.e., scoops) loaded on the ship (Tons_OrderedSL/50). The batching is necessary to assure that all the scoops for the order have completed the conveyor transfer. The batched entity is then attached with the parent entity, or the ship, to indicate that all the ordered coal has been loaded onto the ship.

During the simulation, an graphical icon in the form of a triangle moves along the ConveyorB line to symbolize the movement of a Scoop_Coal entity. ProcessModel continually displays the number of activities in use on the screen to indicate the number of scoops on the conveyor. Similar ProcessModel logic is used with scoops of coal for the unloading and loading of coal off and on barges and trains.

Model Modularity

As a result of the model modularity (Reference Figure 4) the basic conceptual framework has been successfully and rapidly adapted to three other domains 1) container terminal at a seaport served by ship, train and truck, 2) inland intermodal terminal center served by air, train and truck and 3) security container inspection. The three simulation models were written in ProcessModel and are briefly discussed in the following paragraphs.

The container terminal model is a simulation of the Choctaw Point container terminal that is under construction at the Alabama State Docks in Mobile, Alabama and consisted of 5 submodels (Harris et.al. 2007b). The state dock was very interested in validation of 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 second simulation model was to evaluate the operations of the container facility at the International Intermodal Center in Huntsville, AL and consisted of 7 submodels (Harris et.al. 2007b). 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 simulation results indicated that 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

The third simulation model was to determine the resources needed to minimize the disruption resulting from increased security inspection of containers at an intermodal terminal and consisted of 7 submodels (Schroer, et.al. 2008). The initial simulation run started intentionally with a large number of resources. Additional simulation runs were made with a continual reduction of resources until entity throughput at the terminal dropped below allowed limits. Simulation Run9 with six tailgate inspection stations, three intensive inspection stations and one general purpose inspector was the minimum resources necessary to not disrupt container throughput.

The use of modular submodels in the simulations significantly reduced the time to develop the additional simulations. Furthermore, the time was minimal for model debugging and for model verification and validation.

AREAS FOR MODEL REFINEMENTS

As with all simulation model developments there are always a number of refinements that could be made to improve model performance and accuracy. These refinements are generally relatively easy to implement within the ProcessModel environment. One model refinement is that the model assumes the coal car flipper flips all coal cars before the coal is moved on the conveyor to the coal pile. This causes a slight error in the time before the coal actually arrives at the coal pile. Instead a coal car should be flipped and the coal in that car immediately moved to the coal pile.

A second refinement is that the coal terminal has more coal piles than just the low sulfur and high sulfur piles. Some customers want a specific coal mix. As a result, other coal piles are created by pulling coal from several piles. A third refinement is the model will load an empty barge whenever there is sufficient low sulfur coal available. However, the loading of barges is based on customer orders.

CONCLUSIONS

As a result of the presentation made here, the authors propose the following conclusions:

- The protocol for the use of tugboats is critical to increasing terminal throughput. Protocol A resulted in almost 100% utilization of the ship and barge tugboats; however with very little coal throughput.
- Protocol B for Run1 resulted in much lower utilizations of the ship and barge tugboats and very large coal throughput.
- Run1 (simulation run length of six months) with one ship tugboat and two barge tugboats achieved the loading of 8,200,000 tons of high sulfur coal and 6,700,000 tons of low sulfur coal. On an annual basis, this equates to 29,800,000 (assuming 24 hours/day operations).
- An increase in the number of ship tugboats and/or barge tugboats (Runs 2-5) slightly reduced average tugboat utilizations and did not significantly increase coal throughput.
- Run3 with three ship tugboats and two barge tugboats resulted in one of the lowest times for unloading and loading ships. The average time was 13,098 minutes as compared to 15,951 minutes for Run1. However, the average utilization of the three ship tugboats was only 65%, and 58% for the two barge tugboats.
- A change in the ship protocol in Run3B and a reduction of the number of tugboats to one ship tugboat and two barge tugboats did not affect throughput. However, ship tugboat utilization dropped from 84% with three tugboats for Run3A to 2% with one tugboat for Run3B. Barge tugboat utilization remained constant at 68% for both runs.
- When entities (ships, barges and trains) arrive at the terminal, resources are needed immediately to unload and/or load coal. As a result, utilization of resources is high at that particular time. Once an entity leaves the terminal, the utilization of the model resources significantly drops. Consequently, looking at only average utilizations may be misleading. A look at peak need resources may be more revealing.

- Run3A reveals the interactions and constraints between the various submodels. Making a change in one submodel may or may not have a significant impact on another submodel due to the situation where each model was individually developed and then linked together, thus, the desired results may not be achieved.

In conclusion, the protocol used by State Docks' personnel is a very critical factor in ship tugboat and barge tugboat utilization. This protocol hinges on making certain the availability of a ship berth or a barge berth before calling for a corresponding tugboat. The protocol for Run3B along with one ship tugboat and two barge tugboats resulted in the largest coal throughput.

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