Coal Terminal Simulation

Gregory A. Harris, Anthony Holden and Bernard J. Schroer
University of Alabama in Huntsville; Huntsville, AL 35899
harrisg@uah.edu

Dietmar P.F. Moeller
University of Hamburg; Hamburg, Germany

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ABSTRACT
This paper presents a simulation model representation of the McDuffie coal terminal at the Alabama State Docks in Mobile, Alabama. Included in this paper are a description of the coal terminal, the conceptual framework of the model and an analysis of the simulation results.

KEYWORDS
Coal terminal, docks, ports, discrete event simulation

INTRODUCTION

The McDuffie Coal Terminal at the Alabama State Docks in Mobile, Alabama consists of 556 acres and is the largest coal terminal on the gulf coast and the second largest in the U.S. Total tonnage through the terminal for FY05 was 15,500,000 tons. Total ground capacity is 2,300,000 tons. Annual throughput capacity is 20,000,000 tons.

The McDuffie Coal Terminal was established in 1976 as an export facility. In 1998 the facility began importing low sulfur coal for use at power generation plants.

A major customer would like to see the volume increased to 30,000,000 tons annually. The systems and equipment at the coal terminal have evolved over the years resulting in inefficiencies in the operational activities 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.

Figure 1 is one of the coal piles and one of the reclaimers used for dispensing coal to the inventory piles for storage and for reclaiming coal from the inventory piles for shipment.

Management of the port was presented with the principles of lean manufacturing and agreed to try this at the McDuffie Coal Terminal The concepts of lean manufacturing (NIST, 1998) are to identify and eliminate inefficiencies, termed waste, in a process. The waste can be categorized into overproduction, inventory, defects, motion, transportation, waiting, extra processing and underutilizing people.

Several of the wastes evident in the operations of the coal terminal are:

- Waste of workers – waiting, rework and inspection
- Waste of machines – setup and breakdown
- Waste of materials – transport and storage
- Waste of information – order processing

These wastes are non-value adding activities that should be minimized or eliminated. A non-value added activity is defined as anything that the customer will not pay for. Many of the operations that are currently performed at the McDuffie Coal Terminal would not be considered value added. Examples of these non-value added activities are equipment setup and breakdown, handling and movement of coal throughout the terminal and coal storage. Ideally coal should arrive at the coal terminal and be immediately dispensed to another transportation mode for delivery to the customer.

Figure 1. McDuffie Coal Terminal

Simulation is an excellent tool to explore opportunities for improving processes and minimizing wastes. Simulation is valuable in evaluating proposed improvements before significant time and resources are expended. It is critical to understand the impact of change prior to the expending of resources, especially at a large scale operation such as a coal terminal.

COAL TERMINAL MODEL

Figure 2 is the conceptual framework of the coal terminal model. The model has three submodels: ship unloading and loading of coal; barge unloading and loading of coal; and train unloading and loading of coal.

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 terminal is modeled with two coal piles, or inventory locations. High sulfur coal arrives on barges and trains and leaves on ships. Low sulfur coal arrives on ships and leaves on barges and trains.

Model resources are:

- Three ship berths
- Three barge berths
- Two cranes for unloading coal onto conveyors
- Two ship unloading conveyors
- One ship loading conveyor
- Two barge unloading conveyors
- Two barge loading conveyors
- Two train unloading conveyors
- One train loading conveyor
- Three train slots (maximum number of trains allowed at terminal)
- Two coal car flippers (grabs car and dumps coal onto conveyor)

Model entities are ships, barges, trains and scoops of coal. The model has 29 entity attributes and eight global variables.

The model has a number of boxes, or ProcessModel Labels, that display outputs during the simulation and are used extensively during model verification and validation. These boxes are:

- Low sulfur coal pile (tons)
- High sulfur coal pile (tons)
- Total coal unloaded from ships (tons)
- Total coal unloaded from barges (tons)
- Total coal unloaded from trains (tons)
- Total coal loaded onto ships (tons)
- Total coal loaded onto barges (tons)
- Total coal loaded onto trains (tons)

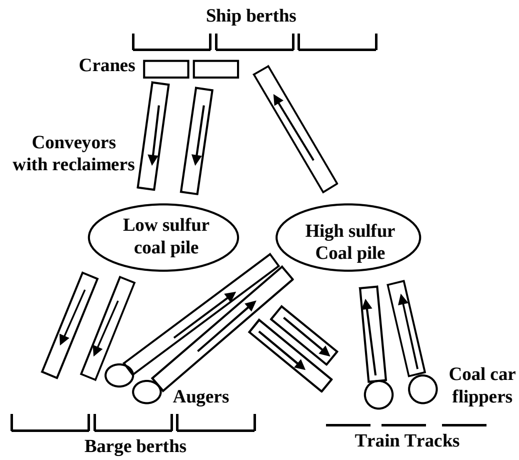

Figure 2. Conceptual framework for coal terminal model

Figure 2 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 in Figure 1 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.

SHIP UNLODING/LOADING SUBMODEL

Figure 3 is the ProcessModel logic for the ship unloading and loading submodel. The comments next to the boxes and lines are the logic in the action section of activities and the attached routing lines. For example, the following comments next to the activity Ship_Enters_Terminal are:

GET Ship_Berth	Seize resource
GET 2 Ship_Crane	Seize two resources
Ship_Tons_In = 75,000	Tons to be unloaded
GET 2 ConveyorA	Seize two resources

Tons_OrderedSU=Ship_Tons_In
Tons to be unloaded

Coal Loading Logic

The ProcessModel logic for the ship coal loading in Figure 4 is as follows. At activity Load_One_Scoop_From_High_S_Pile_Onto_Cnyr one scoop of coal is picked up by the reclaimer and placed on ConveyorB. An entity called Scoop_Coal is created and routed to activity

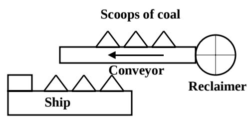

Figure 3. Conceptual framework for loading coal from coal pile onto a ship

Scoop_Of_Coal_Onto_Ship. At the same time the parent entity keeps looping 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 entity in the form of a triangle moves along the ConveyorB line to symbolize the movement of a Scoop_Coal entity. Also, ProcessModel continually displays the number of activities in use on the screen to indicate the number of scoops on the conveyor.

VERIFICATION AND VALIDATION

The model was run for 720 hours (or 30 days) with the following results in the ProcessModel label boxes at time 720 hours, the end of the simulation:

- Low sulfur coal pile 5,315 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.

The total coal unloaded was 1,312,000 tons during one month. This equates to 15,600,000 tons annually which compares to the FY05 tonnage through the terminal of 15,500,000 tons.

ANALYSIS OF RESULTS

A number of Kaizens process improvement events (Ohno, 1988 and NIST, 1998) were conducted at the coal terminal with the goal of improving operations efficiency and increasing productivity. The results of the Kaizens identified equipment Total Productive Maintenance and conveyor operations as two primary areas for improvement. The simulation model was then exercised with various scenarios to address these areas for improvement.

Baseline Run

The baseline consisted of the following input:

- Time between arrivals: Three days for ships, two hours for barges and one day for trains
- Arrival capacity: ship 75,000 tons low sulfur coal; barge 1,500 tons high sulfur coal; train 100 cars, 100 tons/car for total of 10,000 tons high sulfur coal
- Ship crane unloads one simulation scoop of 15 tons per minute
- Two ship cranes assigned to unloading of a ship along with two conveyors
- Barge auger unloads one simulation scoop of 15 tons per minute
- Train auger unloads one simulation scoop of 15 tons per minute
- Ship reclaimer loads one simulation scoop of 50 tons per minute
- Barge reclaimer loads one simulation scoop of 50 tons per minute
- Train reclaimer loads one simulation scoop of 50 tons per minute

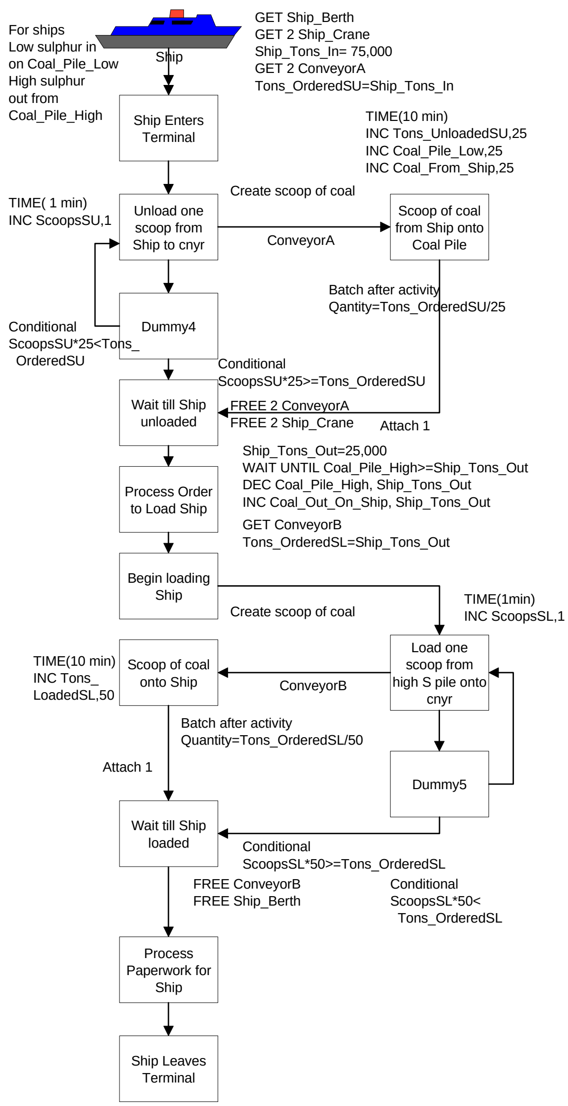

Figure 3. Ship Unloading/Loading submodel

- Departure capacity: ship 75,000 tons high sulfur coal, barge 1,500 tons low sulfur coal, train 10,000 tons low sulfur coal
- Time for scoop of coal from ship to coal pile and coal pile to ship 10 minutes each
- Time for scoop of coal to travel from barge or train to coal pile 6 minutes
- Time for scoop of coal to travel from coal pile to ship or train 5 minutes
- Time for any scoop of coal to be placed on conveyor is one minutes
- Three ship berths for loading and unloading
- Three barge berths for loading and unloading
- Space for three trains at a time
- Two coal car flippers
- Two conveyors for ship unloading
- One conveyor for ship loading
- Two conveyors for barge unloading
- Two conveyors for barge loading
- Two conveyors for train unloading
- One conveyor for train loading

In addition, the simulation started empty and idle; no ships, barges and trains were initially at the terminal; and all coal piles were empty.

The baseline simulation results after running for 720 minutes are:

- Utilization of resources

Ship berths (three)	65%
Barge berths (three)	54%
Train slots (three)	96%
Ship crane (two)	100%
Ship unload conveyors (two)	100%
Ship load conveyor (one)	28%
Barge unload conveyors (two)	52%
Barge load conveyors (two)	18%
Train unload conveyor (two)	14%
Train load conveyor (one)	9%
Coal car flipper (two)	4%

- Time through the terminal (value added time only)

Ship	6,560 minutes
Barge	190 minutes
Train	1,417 minutes

- Ships through terminal 8
- Barges through terminal 359
- Trains through terminal 10

Impact of Process Improvements(Runs 1-2)
As a result of the Kaizens a number of process improvements were made to the unloading of coal from ships, barges and trains. Consequently, Table I outlines the runs to evaluate these improvements:

Table I. Additional runs

	Crane Unload Scoop	Barge Unload Scoop	Train Unload Scoop
Baseline	15 tons	15 tons	15 tons
Run1	20 tons	20 tons	20 tons
Run2	25 tons	25 tons	25 tons

For example, the barge and train augers have nine buckets, each holding 0.5 tons. At 5.5 rpms the augur can move 1,500 tons per hour. For simulation purposes, this equates to 25 tons per scoop. At 4.4 rpms the augur can move 1,200 tons per hours.

Some of the resource utilizations for each of the runs are given in Table II. As anticipated the utilizations of the ship and barge conveyors dropped since scoop size increased. However, utilization of the train conveyor increased.

The utilization of all loading conveyors increased because of the large scoops at unloading. More coal was unloaded resulting in more coal at the coal piles for loading. Also there were ships, barges and trains available for loading which resulted in greater conveyor utilizations.

Table II. Resource utilizations (%) for runs

	Baseline	Run1	Run2
Ship berths	65	40	35
Barge berths	54	52	63
Train slots	96	90	82
Ship cranes	100	87	70
Ship unload conveyors	100	87	70
Ship load conveyor	28	32	34
Barge unload conveyors	52	42	35
Barge load conveyors	18	18	18
Train unload conveyor	14	22	20
Train load conveyor	9	20	21
Coal car flipper	4	8	8

Table III gives the tonnage unloaded and loaded for each run. As scoop size increased less time was required to unload a ship, barge or train. Likewise, tonnage unloaded increased provided there were sufficient coal arrivals.

Table III. Tonnage unloaded and loaded

	Baseline	Run1	Run2
Ship			
Unloaded	643,815	750,000	750,000
Loaded	600,000	750,000	750,000
Barge			
Unloaded	539,895	540,000	534,000
Loaded	538,500	540,000	540,000
Train			
Unloaded	130,065	240,000	250,000
Loaded	100,000	210,000	220,000

Table IV gives the times in the system for the Baseline and Runs1-2.

As anticipated, the time in the system decreased as the unload scoop size increased. For example, the time to unload and load a ship reduced from 6,560 minutes to 4,560 minutes, or a 30% reduction. The value added time for barges reduced from 190 minutes to 150 minutes, or a 21% reduction. The value added time for trains reduced from 1,417 minutes to 1,150 minutes, or a 19% reduction.

Table IV. Times in the system

	Baseline	Run1	Run2
Scoop size	15 ton	20 tons	25 tons
Ships			
Number	8	9	9
Time in system	9,106 min	5,368 min	4,714 min
Value added time in system	6,560 min	5,310 min	4,560 min
Barges			
Number	359	359	353
Time in system	246 min	248 min	412 min
Value added time in system	190 min	165 min	150 min
Trains			
Number	10	21	22
Time in system	16,233 min	7,314 min	5,777 min
Value added time in system	1,417 min	1,250 min	1,150 min

Modification to Baseline (Run3)
The initial baseline model started empty and idle and with all coal piles empty. The revised model (Run3) started with 25,000 tons in each coal pile.

The barge berths in Run2 were utilized 63%, barge unload conveyors 35% and barge load conveyors 18%. Therefore, a logical area to increase throughput is the barge area. McDuffie terminal currently has a pool of empty barges available to fill orders. Run3 has the additional ProcessModel logic for the arrival of six empty barges every twenty-four hours.

The results of Run3 after running for 720 minutes are:

- Utilization of resources

Ship berths (three)	55%
Barge berths (three)	55%
Train slots (three)	91%
Ship crane (two)	70%
Ship unload conveyors (two)	70%
Ship load conveyor (one)	28%
Barge unload conveyors (two)	36%
Barge load conveyors (two)	25%

Train unload conveyor (two)	4%
Train load conveyor (one)	2%
Coal car flipper (two)	2%

- Barges unloaded and loaded 328 (492,000 tons)
- Empty barges loaded 168 (252,000 tons)
- Ships unloaded and loaded 8
- Trains unloaded and loaded 3
- Coal from ships 750,000 tons
- Coal from barges 540,000 tons
- Coal from trains 60,000 tons
- Coal out on ships 600,000 tons
- Coal out on barges 744,000 tons
- Coal out on train 30,000 tons
- Low sulfur coal pile 1,000 tons
- High sulfur coal pile 25,000 tons
- Time through the terminal

Ship	7,470 minutes
Barge	1,659 minutes
Empty barge	1,599 minutes
Train	2,208 minutes

- Time through the terminal (value added time only)

Ship	4,560 minutes
Barge	150 minutes
Empty barge	80 minutes
Train	1,150 minutes

The results indicated that the low sulfur coal pile did not contain sufficient coal to load the empty barges. The number of barges loaded increased significantly to 496 (328+168) up from 353 in Run2. On the other hand, the number of trains loaded decreased significantly to three down from 22 in Run2. It appears that the ProcessModel logic processed the empty barges rather than the trains.

Increase Ship Arrivals (Run4)
It appears that a constraint is the low sulfur coal pile. Therefore, to increase barge throughput requires more low sulfur coal arriving from ships. The ship unload conveyor utilization is 70% and the ship berth utilization is only 55% indicating that additional low sulfur coal could be added to the coal pile (See Run3).

Run4 has ships arriving every two days rather than three days. The results after running for 720 minutes are:

- Utilization of resources

Ship berths (three)	83%
Barge berths (three)	42%
Train slots (three)	51%
Ship crane (two)	90%
Ship unload conveyors (two)	90%
Ship load conveyor (one)	35%
Barge unload conveyors (two)	36%
Barge load conveyors (two)	26%
Train unload conveyor (two)	19%
Train load conveyor (one)	20%
Coal car flipper (two)	8%

- Barges unloaded and loaded 348 (522,000 tons)
- Empty barges loaded 174 (261,000 tons)
- Ships unloaded and loaded 10
- Trains unloaded loaded 21
- Coal from ships 971,050 tons
- Coal from barges 540,000 tons
- Coal from trains 240,000 tons
- Coal out on ships 600,000 tons
- Coal out on barges 750,000 tons
- Coal out on train 210,000 tons
- Low sulfur coal pile 50 tons
- High sulfur coal pile 55,000 tons
- Time through the terminal

Ship	8,707 minutes
Barge	491 minutes
Empty barge	404 minutes
Train	1,645 minutes

- Time through the terminal (value added time only)

Ship	4,560 minutes
Barge	150 minutes
Empty barge	80 minutes
Train	1,150 minutes

Ship berth utilization increased to 83% up from 55% for Run3. The ship unload conveyor utilization reached 90% up from 70%. The number of barges loaded increased slightly to 522 (348+174) up from 496. More significantly, the number of trains loaded increased to 21 up from 3 for Run3. This increase in trains loaded resulted from empty trains waiting for low sulfur coal and the increase in the low sulfur coal pile.

AREAS FOR MODEL REFINEMENTS
The model inputs are all constants. Variability could be added by replacing the constant times with distributions.

The model assumes that 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.

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 bulldozers mixing the coal.

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

ProcessModel and the coal terminal model are on a dedicated computer at the University of Alabama in Huntsville. The computer is connected to the Internet. Remote access is accomplished by clicking on the "Remote Desktop Connection."

In summary, the following conclusions are made:

- The simulation model was rapidly constructed using ProcessModel. On the other hand, model verification and validation was rather lengthy. The use of ProcessModel labels greatly improved the V&V process.

- ProcessModel logic was constructed to simulate coal movement on conveyors. However, another package such as ProModel could more visually model the coal handling conveyors.

- The use of Kaizens to target the analysis is an excellent approach to obtain significant impacts from the simulation model. The ship, barge, and train unloading functions were identified as areas for improvement at the coal terminal. Runs1 and 2 evaluated the greater conveyor loading capacities.

- The coal terminal model appears to be very sensitive to interactions between the unloading and loading of ships, barges and trains.

- Low utilization of resources do not necessary indicate areas for improvement. Other constraints may be the cause. For example, if the time between ship arrivals is three days and a ship can be unloaded in two days, then there is a day that the ship berths, ship cranes and supporting conveyors are idle.

- Based on Run4 the coal terminal can unload 21M tons and load 19M tons annually. Because of the nearly 100% utilization of several of the resources, it appears that the goal of 30M tons annually may not be possible without an equipment upgrade.

ACKNOWLEDGEMENTS

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AUTHOR BIOGRAPHIES

Greg Harris is Director of the Alabama Technology Network Center and Deputy Director of the Office for Economic Development at UAH. Harris is a certified NIST lean manufacturing trainer. Harris has a PhD in Industrial and Systems Engineering from UAH and is a registered Professional Engineer.

Anthony Holden is a Research Scientist at UAH. Holden is a certified NIST lean manufacturing trainer. Holden has a BS in Industrial and Systems Engineering from UAH and is a pursuing a MS in Engineering Management.

Bernard Schroer is a Principal Research Engineer at UAH. He is a Fellow of IIE, a Fellow of the SME and a member of SCS. He has a Ph.D. in Industrial Engineering from Oklahoma State University and is a registered Professional Engineer.

Dietmar Moeller is Professor of Computer Science and Computer Engineering at the Mathematics, Computer Science and Science Faculty of the University of Hamburg, Germany. His is also Chair of Computer Engineering.