

A Simulation Approach to Evaluating Productivity Improvement at a Seaport Coal Terminal

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The use of simulation in evaluating the impact of productivity improvement activities at the McDuffie Coal Terminal located at the Alabama State Docks in Mobile, Alabama, is discussed. Simulations are being employed for port and terminal operations at an increasing rate because of the value derived as decision support tools. A description of the productivity improvement events, the conceptual framework of the simulation model, and an analysis of the simulation results are presented.

Simulation is being applied to a wide range of port operations and terminal planning processes and is an excellent tool to evaluate the impact of opportunities for improving processes and minimizing wastes (1). Simulation is valuable in evaluating proposed improvements before significant time and resources are expended. Models of port and terminal operations have become very valuable as decision support tools (1). It is critical to understand the impact of change before the expending of resources, especially at a large-scale operation such as a coal terminal.

Lean manufacturing embodies a philosophy of eliminating all non-value-added activities (or waste) in a process and creating value for customers. It is a culture in which all employees are continuously looking for ways to improve processes. The concepts of lean manufacturing, or continuous improvement, are now being successfully applied outside manufacturing in such areas as the office, procurement, logistics, inventory management, maintenance and repair, city government, education institutions, and medicine. This paper summarizes the application of lean principles to a coal terminal.

The key to lean manufacturing is to compress time by eliminating waste and thus continually improving the process. The essential elements of process improvement are the elimination of waste (non-value-added activities) through value stream mapping, workplace organization and the 5S system, and standardization of procedures. Several continuous improvement tools are shown in Figure 1 and defined in Table 1. A number of books have been written describing these tools (2–11).

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A common method of implementing lean manufacturing principles is through the use of kaizen events (3, 5, 8, 12). Kaizen is a Kanji character for continuous improvement (kai = change, zen = excellent). The typical steps in a kaizen event are as follows (3, 5):

- Observe the process,
- Sketch the layout and define the work sequence,
- Collect all cycle times,
- Brainstorm opportunities for improvement (including a gap analysis),
- Prioritize and select the top opportunities,
- Brainstorm suggestions for improvement (develop counter-measures),
- Prepare cost and benefit analysis, and
- Try the improvements on process.

McDUFFIE COAL TERMINAL

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

The systems and equipment utilized at the coal terminal have evolved over the years resulting in inefficiencies in the operational activities and processes. The condition of equipment and processes, along with customer requirements for increased coal volume, led management to seek out opportunities to improve operational efficiency, system productivity, and throughput of coal. The management team at the port became aware of the principles of lean manufacturing and continuous improvement through a series of meetings and agreed to try the approach at the McDuffie Coal Terminal. The concepts of continuous improvement are embodied in the fundamentals of lean thinking (12):

- Specify value as defined by the customer,
- Identify the value stream (the end-to-end linked actions),
- Make the value flow continuously,
- Let customers pull the value through the value stream, and
- Pursue perfection through continuous improvement.

The main focus of a continuous improvement culture is to identify and eliminate inefficiencies, termed waste, in a process and to create value in the eyes of the customer (5, 6, 8, 12). The waste can be categorized into overproduction, inventory, defects, motion, transporta-

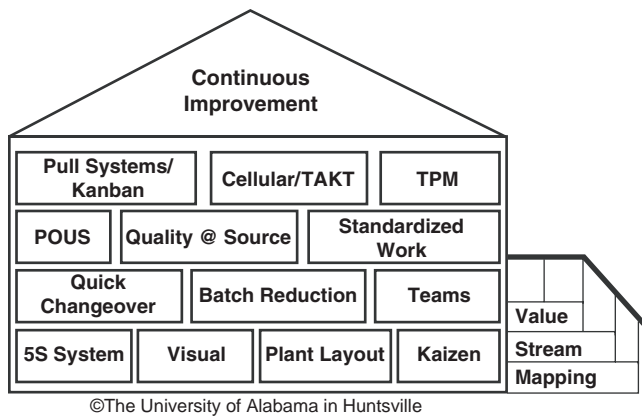


FIGURE 1 Lean tools.

tion, waiting, overprocessing, and underutilizing people. Several of the wastes evident in the operations of the coal terminal are as follows:

- Waiting,
- Defects,
- Motion,
- Transportation,
- Overprocessing, and
- Underutilized people.

Many operations at the McDuffie Coal 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. Economic conditions within the coal industry make the storage of strategic inventory at the McDuffie Coal Terminal a desirable market smoothing mechanism.

PRODUCTIVITY IMPROVEMENT ACTIVITIES

Eight kaizen process improvement events (5, 6) were conducted at the coal terminal since 2005 with the goal of improving operations efficiency and increasing productivity, throughput, and velocity. Three of the kaizens, chosen to display the capability of the simulation, are summarized below. The results of the kaizens identified barge loading and unloading and ship unloading as primary areas for improvement.

Kaizen 1

The goal of Kaizen 1 was to load barges in 1 h and shift barges into loaders in 5 min.

Opportunities

Opportunities included the lack of standard operating procedures (SOPs); mechanical deficiencies in equipment; poor communication between tugboat, surveyor, draft callers, and operator; poor lighting; and productivity losses at shift change.

Countermeasures

The team developed a SOP for training and management of the operation, repaired hydraulic units, incorporated instructions in the

TABLE 1 Lean Definitions

Tool	Description
5S System—workplace organization	Safe, clean, organized work area. Marked location for everything. Eliminate anything not required to perform the tasks. The 5S's are Sort, Straighten, Scrub/Shine, Standardize, and Sustain.
Batch reduction	Minimize work-in-process by reducing the amount of work released to only that required to meet current demand.
Cellular—TAKT	Cellular operations create a smooth flow that shortens the lead time for delivery while supporting low inventory production, space saving, and continuous improvement. TAKT is the rate of demand and is defined as the available time divided by demand.
Kaizen	Continuous incremental improvement of an activity to create more value with less waste.
Plant layout	Arrangement of equipment to minimize transportation and motion. Allow for easy access to needed materials and tools.
POUS (point of use storage)	Place materials at the point of need or use.
Pull systems—Kanban	The translation of Kanban is card. An information system that controls (pulls) the action, in the required quantity and at the required time.
Quality at source	Source inspection. Inspection takes place at the point of activity.
Quick changeover (single minute exchange of dies or SMED)	Minimize setup time. Quickly changing from one activity to another.
Standardized work	Set way to perform a task, performed in the same manner every time.
Teams	Eliminate department barriers and replace with cross-functional teams that quickly study a process and then implement improvements.
Total productive maintenance (TPM)	Organization-wide equipment maintenance program that covers the entire equipment life cycle and requires participation by every employee.
Value stream mapping	Tool used to map the physical and information flow involved in a process. The purpose is to take a snapshot of the current state of a value stream, identify areas to eliminate non-value-added activities and/or information and then conceive how the process should function (the future state).
Visual controls	Simple signals that provide immediate understanding of situation or condition.

SOPs and purchased radios, installed lights, installed communication boards at loader, and developed a shift change communication form for supervisors.

Kaizen 2

The goal of Kaizen 2 was to unload 35,000 tons per day (average) from the vessel.

Opportunities

Several communication issues delayed ship unloading. Ship unloading was also delayed because of unnecessary steps by crane operators. Other opportunities included several maintenance issues with

equipment, no SOPs, time lost due to idling and minor stoppage, and shift change which resulted in lost productivity.

Countermeasures

The team developed SOPs and a list of maintenance activities that need to be completed. They developed a shift change procedure and a daily maintenance checklist along with a critical spare parts list.

Kaizen 3

The goal of Kaizen 3 was to unload one barge in 60 min.

Opportunities

There were several maintenance issues with the equipment, including that the area and equipment were very dirty. In addition, barge unloading was delayed because of unnecessary steps by barge unloading operators, there were no SOPs, time was lost due to idling and minor stoppages, and the lighting was poor at night so operators could not see the end of the barge.

Countermeasures

The team developed SOPs and daily checklists, installed additional lighting at barge unloading so operators could see the end of the barge at night, developed a list of maintenance activities, cleaned the barge unloading area, and developed a cleaning schedule.

SIMULATION MODEL

Figure 2 presents the conceptual framework of the coal terminal simulation model. The model contains three submodels:

- Ship unloading and loading of coal,
- Barge unloading and loading of coal, and
- Train unloading and loading of coal.

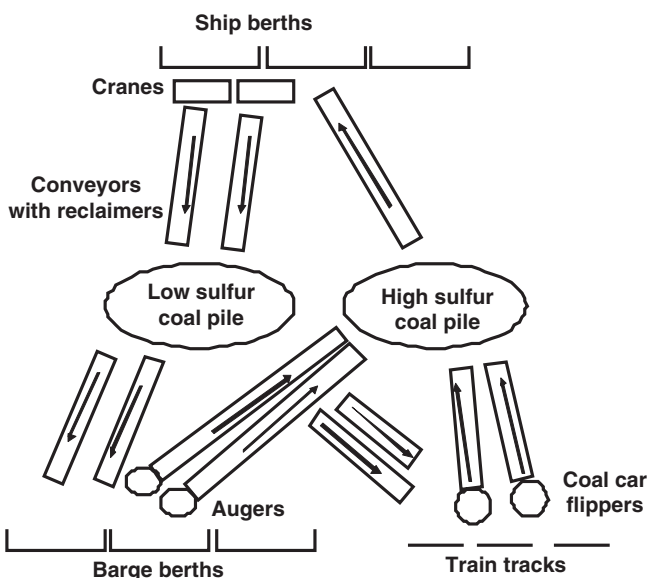


FIGURE 2 Conceptual framework for coal terminal model.

These submodels run independently of one another, each with a different entity such as ship, barge, or train. Data are passed between the submodels by global variables and attributes that are assigned to 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 is exported on ships. Low-sulfur coal is imported on ships and leaves on barges and trains. This is a simplified version of the actual terminal but the scenario allows the simulation to reflect reality in the manner in which the interrelationships occur.

VERIFICATION AND VALIDATION

Model verification is accomplished by determining whether 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. ProcessModel provides a capability in a Label Block feature that displays data from the global variables during the simulation (13). By reducing the speed at which the simulation runs, it is possible to observe these values as entities move through the simulation.

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

- Low-sulfur coal pile, 315 tons;
- High-sulfur coal pile, 4,915 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, 40,020 tons;
- High-sulfur coal out on ship, 600,000 tons;
- Low-sulfur coal out on barge, 658,500 tons; and
- Low-sulfur coal out on train, 10,000 tons.

The total low-sulfur coal arriving, plus initial coal pile volume, minus total low-sulfur coal out should equal current low-sulfur coal pile volume. This calculation $(643,815 + 25,000) - (658,500 + 10,000) = 315$ tons does in fact equal the volume in the current low-sulfur coal pile. The calculation for the high-sulfur coal pile produces the same result $(539,895 + 40,020 + 25,000) - 600,000 = 4,915$ tons.

Several staff members who participated in the kaizen events, and were very familiar with the operations of the McDuffie Terminal, were used in the verification and validation. These staff members observed the running of the simulation, specifically the movement of entities, the coal scoop entities, and the values in the label boxes and determined through their experience that the simulation was performing in a manner that accurately replicated the operations at the physical facility.

BASELINE RUN

The simulation started empty and idle; no ships, barges, and trains were initially at the terminal; and coal piles were 25,000 tons each. The baseline consisted of the following input:

- Time between arrivals: 3 days for ships, 2 h for barges, and 1 day for trains;
- Arrival capacity: ship—75,000 tons of low-sulfur coal; barge—1,500 tons of high-sulfur coal; train—100 cars, 100 tons per car for a total of 10,000 tons of 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;
- Departure capacity: ship—75,000 tons of high-sulfur coal; barge—1,500 tons of low-sulfur coal; train—10,000 tons of low-sulfur coal;
- Time for scoop of coal from ship to coal pile and coal pile to ship: 10 min each;
- Time for scoop of coal to travel from barge or train to coal pile: 6 min;
- Time for scoop of coal to travel from coal pile to ship or train: 5 min;
- Time for any scoop of coal to be placed on conveyor: 1 min;
- Three ship berths for loading and unloading;
- Three barge berths for loading and unloading;
- Space for a maximum of three trains at a time;
- Two coal car flippers;
- Two conveyors for ship unloading, one for loading;
- Two conveyors for barge unloading, two for loading; and
- Two conveyors for train unloading, one for loading.

EXPERIMENTAL DESIGN

The experimental design is given in Table 2. All other data remained the same as the baseline. The Baseline Run 1 defines the coal terminal operations before implementing any of the kaizen results. The results of the kaizens identified equipment total productive maintenance and conveyor operations as two primary areas for improvement. The approach to simulating the impact of greater conveyor uptime and increased capacity was to vary the size (i.e., tonnage) of the simulation scoop. This simulation scoop can also be considered as the maximum loading or unloading capacity. Consequently, Runs 2 to 9 provide the impact of a continual increase in scoop size and likewise conveyor capacity.

TABLE 2 Experimental Design

	Scoop Size Load (tons)	Scoop Size Unload (tons)
Run1 baseline	40	15
Run2	40	20
Run3	40	25
Run4	45	15
Run5	45	20
Run6	45	25
Run7	50	15
Run8	50	20
Run9	50	25

TABLE 3 Tonnage Unloaded and Loaded

	Unloaded (tons)	Load (tons)	Coal Pile (tons)
Run1	1,223,730	1,268,500	5,230
Run2	1,340,000	1,374,000	15,500
Run3	1,350,000	1,374,000	26,000
Run4	1,223,730	1,268,500	5,230
Run5	1,340,000	1,374,000	15,500
Run6	1,350,000	1,374,000	26,000
Run7	1,223,730	1,268,500	5,230
Run8	1,340,000	1,374,000	15,500
Run9	1,350,000	1,374,000	26,000

ANALYSIS

Tables 3 to 6 give the results after running the simulation for 720 min or 30 days. Table 3 presents the tonnage unloaded and loaded for each run. The low-sulfur and high-sulfur coal piles each started with 25,000 tons of coal.

Increasing the load scoop size by itself did not increase the total tons unloaded. However, increasing the unload scoop size by itself did increase the total tons unloaded and loaded. At the same time, the high-sulfur coal pile volume increased.

Table 4 provides the average time that an entity was in the terminal. Table 5 shows the corresponding entities through the terminal. For a ship, this total includes the time entering and leaving the terminal, unloading and loading coal, and any delays waiting for a resource or an activity.

As before, an increase in the load scoop size by itself did not decrease the time that entities were in the terminal. Increasing the unload scoop size by itself did decrease the time that entities were in the terminal. There is some concern that the small number of train entities through the terminal may not provide a large enough sample to be a precise representation.

Table 6 shows the utilization of resources. The utilizations of the ship cranes and ship unload conveyors were 100% for Runs 1, 4, and 7. Increasing the unload scoop size to 20 tons reduced the ship cranes and ship unload conveyors to 87%. The utilization dropped

TABLE 4 Average Time Entity in Terminal (min)

	Ships	Barges		Trains
		Full	Empty	
Run1	9,420	4,042	3,859	1,560
Run2	7,865	1,531	1,428	1,394
Run3	7,825	1,653	1,593	2,308
Run4	9,219	4,038	3,855	1,504
Run5	7,657	1,527	1,424	1,337
Run6	7,617	1,649	1,589	2,205
Run7	9,065	4,048	3,864	1,460
Run8	7,510	1,537	1,432	1,294
Run9	7,470	1,659	1,599	2,208

TABLE 5 Entities Through Terminal

	Ships	Barges		Trains
		Full	Empty	
Run1	7	288	150	1
Run2	7	335	168	2
Run3	8	328	168	3
Run4	7	288	150	1
Run5	7	335	168	2
Run6	8	328	168	3
Run7	7	288	150	1
Run8	7	335	168	2
Run9	8	328	168	3

to 70% for load scoop size of 25 tons. Therefore, it appears that additional ship capacity is possible with the larger scoop sizes.

Run 8 appears to perform the best. The results for Run 8 are given in Table 7.

ADDITIONAL RUNS

Based on the results of Runs 1 to 9, two additional runs were made to determine if the terminal is capable of handling more coal:

- Run 10—Time between arrivals of ships: 3,600 min, or 2.5 days and
- Run 11—Time between arrivals of ships: 2,880 min, or 2.0 days.

These runs are a modification to Run 8 (unload scoop size 50 tons and load scoop size 20 tons). All other data remained constant. The rationale for these additional runs is that there should be an increase in utilization of barge berths and conveyors and train slots and conveyors, and there should be more ships to take the high-sulfur coal out and thus reduce the buildup of the high-sulfur coal pile. The results of Runs 10 and 11 are presented in Table 8.

Reducing the time between arrivals did not increase throughput. However, the time that ships were in the terminal increased from 9,069 to 11,589 min. This is due to the already high utilizations in

Run 11 of ship berths (87%), ship cranes (94%), and ship unload conveyors (94%).

At the end of the simulation for Run 10, there were 24 barges in the queue at the activity Begin_Loading_Barge because the low-sulfur coal pile was down to 740 tons. In addition, the three resources Train_Slot were 89% utilized because of the delay caused by waiting for low-sulfur coal.

CONCLUSIONS

In summary, the authors present the following conclusions.

A kaizen goal was to unload 35,000 tons of coal per day from ships. The simulation results (Run 10) average 27,000 tons per day. It appears that the volume unloaded, simulated by scoop size, may be a limiting factor in the model. The limitation in the model is possibly due to the volume of coal supplied to the terminal as a result of the timing of the arrival of ships and the berth utilization that is generated from the time it takes to unload a ship.

A kaizen goal was to unload or load a barge in 1 h. The simulation results were 492 min (Run 10). The value-added time was 165 min or approximately 80 min to either load or unload a barge. The non-value-added time could be attributed to a lack of resources or delays. Though the barge operations, in actual implementation of the kaizen improvements, were able to achieve the less than 60-min goal, the operations have not sustained that level. The actual achieved level of operation is closer to the 80 min that the simulation suggested as a steady state. This is an interesting outcome of the simulation. The model experiences slight variations in the interrelationships of the operations and thus constrained the model from achieving capacity. This modeling phenomenon relates directly to the communication issues that the kaizen teams identified as ongoing problems. Thus, the model seems to be replicating reality.

The number of trains through the terminal was rather low. It appears that priority in the model was given to barges. The ProcessModel logic needs to be investigated and possibly modified to correct the situation. The ProcessModel logic for barges freed the resource Barge_Berth after being unloaded to accommodate the arrival of empty barges. However, the logic does not free the resource Train_Slot until after both unload and load. It appears that the barges were loaded before the trains possibly because of the lower tonnage on a barge (1,500 tons) than on a train (10,000 tons).

TABLE 6 Resource Utilization

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
Ship berths (3)	70	62	57	69	61	56	68	60	55
Barge berths (3)	48	43	39	47	41	37	50	45	41
Train slots (3)	94	92	91	94	91	91	94	91	91
Ship cranes (2)	100	87	70	100	87	70	100	87	70
Coal car flipper	1	1	2	1	1	2	1	1	2
Conveyors									
Ship unload (2)	100	87	70	100	87	70	100	87	70
Ship load (1)	31	33	34	27	29	30	25	27	28
Barge unload (2)	52	42	36	52	42	36	52	42	36
Barge load (2)	19	22	22	17	20	20	22	26	25
Train unload (1)	4	4	4	4	4	4	4	4	4
Train load	1	2	3	1	2	3	1	1	2

TABLE 7 Results for Run 8

Time at terminal for	
Ships	7,510 min
Barges (full)	1,537 min
Barges (empty)	1,432 min
Trains	1,294 min
Utilizations	
Ship berths (3)	60
Barge berths (3)	45
Train slots (3)	91
Ship cranes (2)	87
Conveyors	
Ship unload (2)	87
Ship load (1)	27
Barge unload (2)	42
Barge load (2)	26
Train unload (4)	4
Train load (1)	1
Coal car flipper	1

NOTE: 1,340,000 tons unloaded; 1,374,000 tons loaded.

When entities (ships, barges, and trains) arrive at the terminal, resources are needed immediately to unload and load coal. As a result, utilization of resources is high. Once an entity leaves the terminal, the utilization of resources drops considerably. Consequently, looking at only average utilizations may be misleading.

On the basis of the runs of the simulation model, it appeared that Run 8 resulted in the greatest throughput of coal unloaded and

loaded. More importantly, the coal was unloaded and loaded in the shortest time. For Run 8 there were no bottlenecks waiting for resources such as cranes and conveyors. In addition, Run 8 mirrored the recommendations of the kaizen events.

The Alabama State Docks implemented most recommendations of the eight kaizens at minimum costs and with very little capital expenditures. For example, several of the recommendations were to develop standard operating procedures, a list of maintenance activities, shift change procedures, daily maintenance checklists, and critical spare parts lists. These recommendations resulted in a reduction in the unloading and loading of 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 into 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 Alabama State Docks has realized a significant increase in throughput capacity and a corresponding reduction in operating costs.

In conclusion, the use of simulation with kaizen events

- Can provide a quick evaluation and validation of kaizen recommendations before implementation;
- Identifies possible bottlenecks overlooked during the kaizen process;
- Allows management the opportunity to see by using computer animation the operation and corresponding impact of the kaizen improvements; and
- Is inexpensive insurance against possible costly mistakes.

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TABLE 8 Results from Runs 10 and 11

	Run 10	Run 11
Unloaded tons	1,436,740	1,436,740
Loaded tons	1,431,000	1,431,000
Coal pile		
Low sulfur	740	740
High sulfur	55,000	55,000
Time at terminal (minutes)		
Ships	9,069	11,589
Barges (full)	492	492
Barges (empty)	437	437
Trains	9,349	9,349
Throughput		
Ships	8	8
Barges (full)	339	339
Barges (empty)	174	174
Trains	6	6
Utilization		
Ship berths (3)	78	87
Barge berths (3)	45	45
Train slots (3)	89	89
Ship cranes (2)	94	94
Conveyors		
Ship unload (2)	94	94
Ship load (2)	28	28
Barge unload (2)	42	42
Train unload (2)	8	8
Train load (1)	5	5
Coal car flipper	3	3

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