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EVALUATING PROPOSED CAPITAL AND OPERATIONAL IMPROVEMENTS AT A MARINE TERMINAL

Scott J. Bury
Naoko Akiya

Engineering and Process Sciences
2301 N. Brazosport Blvd
The Dow Chemical Company
Freeport, TX 77541 U.S.A.

ABSTRACT

Marine terminal operations are complex, and evaluating changes is best done using a simulation tool that captures the dynamics and interactions of the system. We have developed a flexible and robust discrete-event simulation of a marine terminal that handles liquid cargo. We used this simulation to investigate proposed changes generated by a Six Sigma project to reduce congestion at the terminal. Our study provided quantitative data to base decisions on the expected operational and financial impact of the proposed changes. The simulation captured the important details of the system and increased the Six Sigma team's confidence in their recommendations. The modular architecture of the simulation allows for easy application of the simulation to different terminal simply by changing a few data tables. The structure of the simulation makes it easy for non-modelers to use the tool to perform continuing studies.

1 INTRODUCTION

The Six Sigma process can generate a large number of possible solutions to a problem. As part of the Improve Phase of the project, discrete-event simulation is often a successful way to evaluate the potential benefit of the solutions and the likelihood of success. A recent Six Sigma project at Dow Chemical's Texas Operations identified several improvement opportunities for further investigation. We developed a realistic discrete-event simulation of the terminal operations and used the simulation to help evaluate these proposed capital improvements and operational changes.

Texas Operations is Dow Chemical's largest integrated manufacturing site. The marine terminal is a liquid-only terminal that handles both barges and oceangoing vessels, which represent trade lane, spot, and customer pickup orders. Forty-five different products are loaded at the terminal, and four are discharged. Vessels can load any number of products (typically one to ten different products) and parcel sizes. The yearly oceangoing tonnage is spread over approximately 300 to 500 ships and serviced at three different docks.

In our study, we evaluated thirteen different proposed capital changes and a number of operational changes at the marine terminal. The capital changes ranged from installations or upgrades of equipment all the way to the construction of a new dock. The operational changes included evaluating methods of ordering or prioritizing ships, sampling protocols, and other vessel-specific tasks. Those changes were aimed at reducing the yearly demurrage charges and at reducing the overall cycle time to service the ships, thus increasing the potential throughput of the terminal.

The study was successful in valuing the impact of the proposed capital changes and providing financial information in terms of the return on investment. It also provided a way to set the expectations for the improvements from the operational changes. The design of the simulation allows for continued use for testing hypothetical scenarios and responding to future changes in terminal capacity.

The rest of the paper is organized as follows. In section 2 we describe the development of the simulation, including the data analysis and comment on the combinatorial complexity imposed by the fact that the docks are not identical. In section 3 we describe the validation of the simulation. In section 4 we describe the application of the simulation to evaluating the capital and operational improvements. We conclude with a summary of the major findings and learnings.

2 SIMULATION DEVELOPMENT

We had three goals for this study: (1) Develop and a validate a simulation to evaluate the capital improvements and operational changes proposed by the Six Sigma project team, (2) use the simulation to analyze the system performance under various hypothetical scenarios, and (3) develop the simulation in a "sustainable" form so the simulation can be used by operations as needed and so we can rapidly apply it to other marine terminals, with substantially less development time. These goals guided our development process, which is described in the following subsections.

2.1 System Boundaries and Level of Detail

An important early step in all simulation studies is to define the system boundaries carefully. Attempting to model the entire system in infinite detail is counterproductive. This exercise leads to another important step, understanding the expectations of the customer for the simulation deliverables. Good guidelines for scoping and defining simulation projects are readily available, for example in (Law and Kelton 2000) and (Sterman 2000).

We defined the system boundary to include only oceangoing vessels from tendering of Notice of Readiness (NOR) to departure from the terminal. The terminal itself was modeled as three docks based on a generic dock model each with individual characteristics. These characteristics included individual transfer rates of products, vessel preparation time, and type and number of resources available. Product availability was not included in the simulation. External resources like harbor pilots or inspectors were not explicitly included in the model. The proposed capital improvements were simulated in terms of changes in internal resource availability and process delays (e.g. product transfer rates).

These data were gathered with the cooperation of our partners at the marine terminal and documented in a simulation design document. This document provided a reference for us to follow during the simulation development, as well as to ensure that agreement on important points was maintained and expectations met.

2.2 Physical Layout

The terminal consists of three docks, D1, D2, and D3. Figure 1 shows the relative locations of the docks. There are significantly more shore tanks than shown. Dock D1 is the oldest and least technically capable dock. Dock D3 is the most advanced dock and handles the largest number of products. There are some constraints on the physical sizes of the ships and their movement among the docks, but these constraints were not considered in this phase of the study.

2.3 Data Analysis

An advantage for us in the execution of this project was the significant data collection and analysis already done by the Six Sigma team. Thus we were able to begin analyzing the data quickly to develop the key distributions used in the simulation. These distributions included the inter-arrival times of the ships, NOR-to-arrival delays (harbor congestion, pilot limitations, weather), product load preparation delays, and product transfer rates. We used ExpertFit™ and JMP™ to analyze the data.

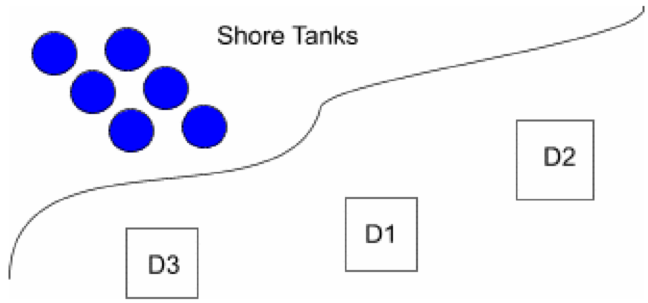

Figure 1: Schematic of the three docks and their relationship to each other and the shore tanks.

2.4 Vessel Specification

The arrival pattern of ships at the terminal is an important factor in evaluating the performance at the terminal. The simulation allows the user to choose between the historical schedule of ship arrivals or a distribution of interarrival times. We found that an exponential distribution with a mean of 22 hours provided an excellent description of the inter-arrival times.

As we mentioned earlier, the oceangoing vessels can load different products during a single visit to the terminal. Certain ships are on contracts and so would typically carry similar cargoes at each visit to the site during the year, while others would be more random in their product mix.

We primarily used the actual product mix and parcel size data for each of the ships arriving in the one-year timeframe for the evaluation of scenarios. We expect that the product mix and load frequency would be similar from year to year because of the integrated nature of the Texas Operations site. We did use the flexible nature of the simulation to examine increases and decreases in the parcel sizes and add spot shipments.

2.5 Product Specification

The way we treat the products in the simulation had a significant impact on our ability to meet our three project goals. We extensively used the embedded database feature of Imagine That, Inc's Extend™ v6 software to create a product-driven simulation instead of a ship- or dock-controlled simulation. At first glance, this approach may seem counterintuitive, since the process of interest is loading and unloading ships at docks. The delay times and resource requirements, however, are tied to product specifications for loading and unloading. One can therefore derive a great deal of information and create a more generic dock by using product specifications to drive the simulation. This approach also allows for easy portability to a different terminal, as we just have to import a new product table to define the dock characteristics.

Figure 2 shows a partial example of a product table. The database table contains product-specific attributes, such as the dock options and the need for shared line resources or vapor recovery resources are readily accessible. The simulation architecture allows easy access to these attributes. The database uses indexing that allows for easy data management. Resources can be labeled to reflect site-specific names, and they can be added or removed easily. This capability increases the readability and usability for the end-user. It also makes it easy to test different scenarios, such as allowing product 7 to be loaded from D1 or D2, as opposed to D1 only, by simply using the dropdown menu as shown in Figure 2.

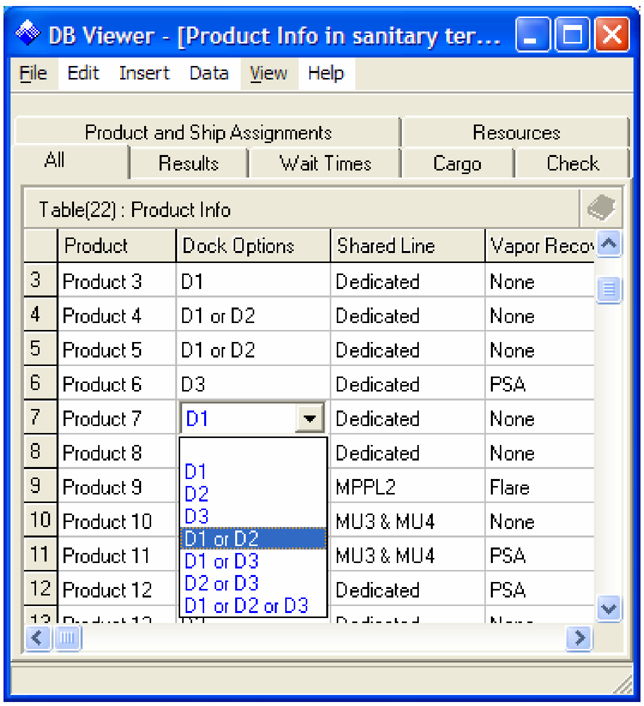

Figure 2: This screenshot of the embedded database shows the product information table.

2.6 Dock Specification

D1, D2, and D3 differ in their capabilities and available resources. The product-driven approach, however, uses generic docks since the product controls the resource requirements. In other words, each generic dock is equipped with all of the resources that are needed by all products, and these resources are turned on or off depending on what products are being loaded. The database controls the number of resources available at each dock, adding another knob to turn to simulate different scenarios. This capability is extremely useful for evaluating hypothetical dock options for each product.

When a ship enters the dock, it is unbatched into individual product items. Products that are not loaded by-pass the loading section. The remaining products to be loaded this voyage are routed through the loading section based on the product specifications for resources. The product parcels requiring these resources are queued, while the rest are prepped and loaded immediately. Long load products are prioritized in the resource queues. This approach accurately captures the parallel and sequential nature of the loading of actual ships as well as the delays in loading caused by waiting for required resources. We can handle any number of products during a load. When all products are loaded, the ship is batched back together into a single entity and proceeds to the next dock or is released to sea.

2.7 Routing Logic

Although the docks in the simulation have identical resources, the products served at each dock are different, which elevates the problem from a simple three-server queue problem to one with more combinatorial complexity. Three different docks results in seven distinct dock options, as seen in the drop-down menu in Figure 2, but are also enumerated in Table 1 below:

Table 1: Seven Options for Loading a Product

Dock Options	
D1	D1 or D2
D2	D1 or D3
D3	D2 or D3
	D1 or D2 or D3

These seven dock options give rise to 127 unique product mixes that can arrive at the dock. For product mixes that are serviced at only one dock, routing is simple. Service at two or three docks increases the number of valid routing options. Cargoes of products with some served at one dock and the others at multiple docks can have greatly increased number of routing options. There are 15 distinct paths available: three single-dock paths, six symmetric two-dock paths, and six symmetric three-dock paths We applied the following business rules to help prioritize the routing: (1) minimize the number of dock visits, (2) load all products possible when at a dock, and (3) load the most products first. Rule number two creates directionality in the routing. For example, if we need to load products with “D1” and “D1 or D2” and “D1 or D3” options, then going to D1 is a single-dock trip but starting at D2 or D3 can be either two- or three-dock trips depending on the next dock selected. Rule number one is overridden only when the lower dock trip numbers are prohibited by excessive queue lengths.

We handle this large number of path options using a filtering system of decision blocks. As each ship comes into the harbor we assign a unique identifier corresponding to its product mix. This identifier is efficiently determined using binary math. This identifier is used to determine a valid route or routes, which are prioritized and chosen according to the business rules. A partial logic table used to develop the routing decision is shown in the appendix. We have since generalized this algorithm to allow for efficiently routing to more than three independent docks.

2.8 Miscellaneous Details

We designed the simulation to be reconfigurable by making selections in the database and switching on/off certain options that exist in the simulation flowsheet. This feature made it easy for the end-users to understand how changes are made in the simulation. We used hierarchical blocks as much as possible in the delivered simulation package. We also took advantage of Extend™'s extensive on-screen documentation, contextual help files and block comment features, which made the simulation logic and flow easy to follow and interpret for the end-users and authors. We applied the principle of common random numbers (Law and Kelton 2000) as much as practical in making comparisons of different scenarios and improvements.

3 VALIDATION

In this section we describe the validation of the simulation. The validation criteria we selected for the simulation were the dock utilization, average wait time, and the total time to serve a specified number of ships compared to historical data. These multiple criteria allowed us to identify areas of the simulation that needed adjustment as different parts of the simulation had different effects on each of the criteria.

The simulation was tested using both the historical schedule and the exponential distribution for the inter-arrival times of the ships. As stated earlier, the makeup of the cargo and the parcel sizes were kept the same as the historical data for each of the ships.

Table 2 shows a comparison of historical data with the two forms of inter-arrival times used in the simulation. The averages and 95% confidence intervals (C.I.) are based on 100 replicates. Utilization is normalized by the historical utilization average of each dock and wait times are normalized by the historical average wait time for dock D1. We had excellent agreement with all three criteria. The higher values for average wait time at D1 and D3 for the random arrivals reflect the highly loaded nature of the dock and show that they can be easily congested. The historical schedule provides a more even spread of the ships throughout the year. Figure 3 shows a plot of the dock utilization throughout the year. The utilization has been normalized by the historical mean at each dock. The plot captures the observed congestion that occurred early in the year. Overall, our clients at the terminal were satisfied that the simulation reflected the operation of the terminal. Perhaps the most important validation criterion is that a simulation can pass the scrutiny of subject matter and operational experts.

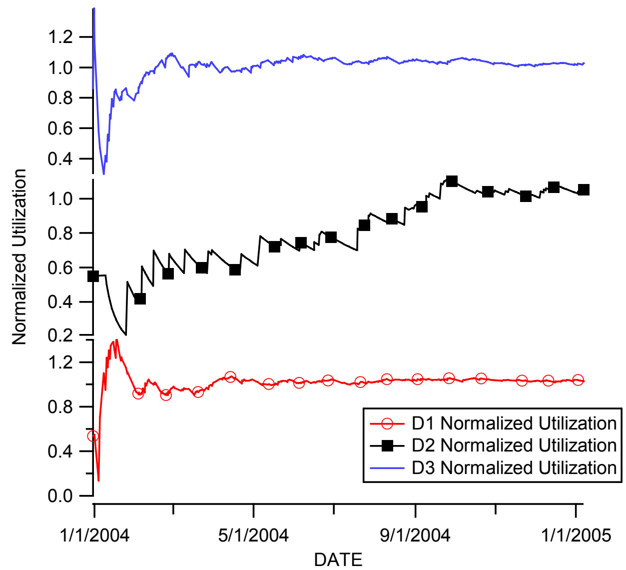

Figure 3: Example of utilization output for the average yearly utilization for the each of the three docks.

4 APPLICATION

In this section, we present the application of the simulation to evaluating two proposed capital changes and the scenario of increased parcel size on the ships. The first capital change involves adding a load a high-volume product, which is currently loaded only at D1 and D3 to dock D2. The second more significant capital change involves adding a fourth dock. The increased partial size was scaled uniformly 10% for all products on all ships. All changes were simulated using the random arrival schedule

4.1 A High-Volume Product at a Third Dock

The flexible nature of the simulation structure allows us simply to change the dock option of this product to "D1 or D2 or D3." The results are summarized in Table 3 and should be compared with the random arrival schedule in Table 2. The data for utilization, wait time, and demurrage costs are included.

The results of the simulation showed that loading this product at D2 in addition to D1 and D3 did indeed increase utilization of D2, but it did little to relieve the congestion at the at the other two docks and slightly increased the total service time. The overall decrease in service cost was not enough to justify the expenditure of capital. The results of the simulation were surprising, since the Six Sigma scorecard had ranked this option high.

Table 2: Results Used for the Validation of the Simulation.

Dock	Average Utiliza-tion	Average Wait Time (hrs)	Demurrage Costs Scaled To Historical =100
D1	1.02±0.01	0.99±0.03	Average 104±2.5
D2	1.09±0.03	2.65±0.18	
D3	1.02±0.01	1.21±0.04	
Dock	**Average Utiliza-tion**	**Average Wait Time (hrs)**	**Demurrage Costs Scaled To Historical =100**
D1	1.05±0.02	1.25±0.06	Average 141±8.0
D2	1.1±0.02	2.38±0.20	
D3	1.02±0.02	2.09±0.06	

Table 3: Results for the High-Volume Product at D2 Scenario with Random Arrival Schedule.

Dock	Average Utiliza-tion	Average Wait Time (hrs)	Demurrage Costs Scaled To Historical =100
D1	1.01±0.02	1.01±0.04	Average 124±6.0
D2	1.28±0.03	2.33±.12	
D3	0.95±0.02	1.21±0.04	

4.2 Increased Capacity Scenario

We tested the current operation against a 10% increase in the parcel sizes and the results are shown in Table 4. These simulations demonstrated that increased wait times occur primarily at D1 and D2. These docks have the longest loading products and largest parcel sizes as a baseline. These results guided further investigation into operational changes to relieve the congestion under the increased parcel size.

4.3 A Fourth Dock with Increased Parcel Sizes

The construction of a new dock is a significant capital investment. From a simulation standpoint, the addition of a fourth dock could create significant routing logic issues. We avoided this complication by creating a dock that is identical to D3 in its current capability and specifying that the products currently loaded at D3 can be loaded at the fourth dock. Thus the three-dock routing logic could be used without change as routes requiring just D3 have two parallel servers instead of a single server. The end-user can activate this new dock by simply activating a switch on the flowsheet.

Results of the simulations with parcel sizes increased by 10% are shown and a 4th dock are given in Table 5. Utilization is normalized by the historical utilization average of each dock and wait times are normalized by the historical average wait time for dock D1. The results of the simulation showed significant decrease in waiting times and hence demurrage cost.

This finding was further tested by turning off D1 and testing against increased parcel sizes. The results of these experiments can be used to determine the economic return on the construction of a new dock and decommissioning of D1.

Table 4: Results for the Increase Parcel Size Scenario with Random Arrival Schedule and Current Operation.

Dock	Average Utiliza-tion	Average Wait Time (hrs)	Demurrage Costs Scaled To Historical =100
D1	1.11±0.03	1.48±0.07	Average 156±8.0
D2	1.19±0.03	2.91±.0.25	
D3	1.03±0.02	2.11±0.13	

Table 5: Results for the New Dock Scenario with Random Arrival Schedule and Increased Parcel Sizes (by 10%).

Dock	Average Utiliza-tion	Average Wait Time (hrs)	Demurrage Costs Scaled To Historical =100
D1	1.06±0.02	1.11±0.03	Average 74±2.5
D2	1.19±0.03	2.90±.0.23	
D3	0.71±0.01	0.31±0.03	
D4	0.39±0.01	0.00±0.00	

5 CONCLUSION

We met the three goals for this study by following a structured approach to the definition of the system boundaries, applying careful data analysis, and designing the simulation to ensure ease of validation and maximum flexibility. The simulation delivered the quantitative measures of the impact of the proposed capital changes and operational changes on dock congestion performance measures. We used the simulation results to determine how much improvement in resource availability or process delays would be necessary to achieve a desired reduction in dock congestion or estimated demurrage cost. From these data, the process owners could evaluate the financial impact and make the final determination of which improvement projects to execute. This approach increased the confidence that the Six Sigma team had in their recommendations.

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APPENDIX

Table A-1 shows a small portion of the logic table used to determine the routing of arriving ships based on their product mix. By assigning 0 or 1 to dock options associated with the products we can build a binary number or use bitwise operations that allows for the rapid assignment of the unique mix identifier. The mix identifier can then be used in decision blocks or in a search table for larger number of docks to select the valid and most efficient routing.

Table A-1: Logic Table for Routing

Dock Options	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
D1 Only	1	0	0	1	0
D2 Only	0	1	0	0	0
D3 Only	0	0	1	0	0
D1 or D3	0	0	0	1	0
D1 or D2	0	0	0	0	1
D2 or D3	0	0	0	0	0
D1 or D2 or D3	0	0	0	0	1
Mix Identifier	**1**	**2**	**4**	**9**	**80**
Route 1	True	False	False	True	True
Route 2	False	True	False	False	True
Route 3	False	False	True	False	False
Route 4	False	False	False	False	False
Route 5	False	False	False	False	False
Route 6	False	False	False	False	False
Route 7	False	False	False	True	True
Route 8	False	False	False	False	False
Route 9	False	False	False	False	True

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BIOGRAPHIES

SCOTT J. BURY is a member of the Modeling group of The Dow Chemical Company's Engineering and Process Sciences organization. His research interests include process simulation of chemical processes using both continuous and discrete event technology. He is a certified Six Sigma Black Belt. He is a member of INFORMS and APICS. His email address is <scott.bury.sb@dow.com>.

NAOKO AKIYA is a member of the Modeling group of The Dow Chemical Company's Engineering and Process Sciences organization. Her research interests include process analysis, problem solving, optimization, and decision analysis. She is a certified Six Sigma Black Belt. She is a member of INFORMS and AIChE. Her e-mail address is <nakiya@dow.com>.