SIMULATION ANALYSIS OF MARINE TERMINAL INVESTMENTS

David W. Graff
Esso Mathematics & Systems Inc.
Florham Park, New Jersey

Abstract

A common problem in the oil industry is the optimization of terminal facilities to minimize delays in servicing incoming tankers. In Exxon Corporation, simulation has been successfully applied to marine terminal studies since the early nineteen sixties. The development of a general model in 1967 contributed to wider use of marine terminal simulation throughout the company. This paper discusses the marine terminal investment problem, the basic technical features of this model, and a typical application of the model.

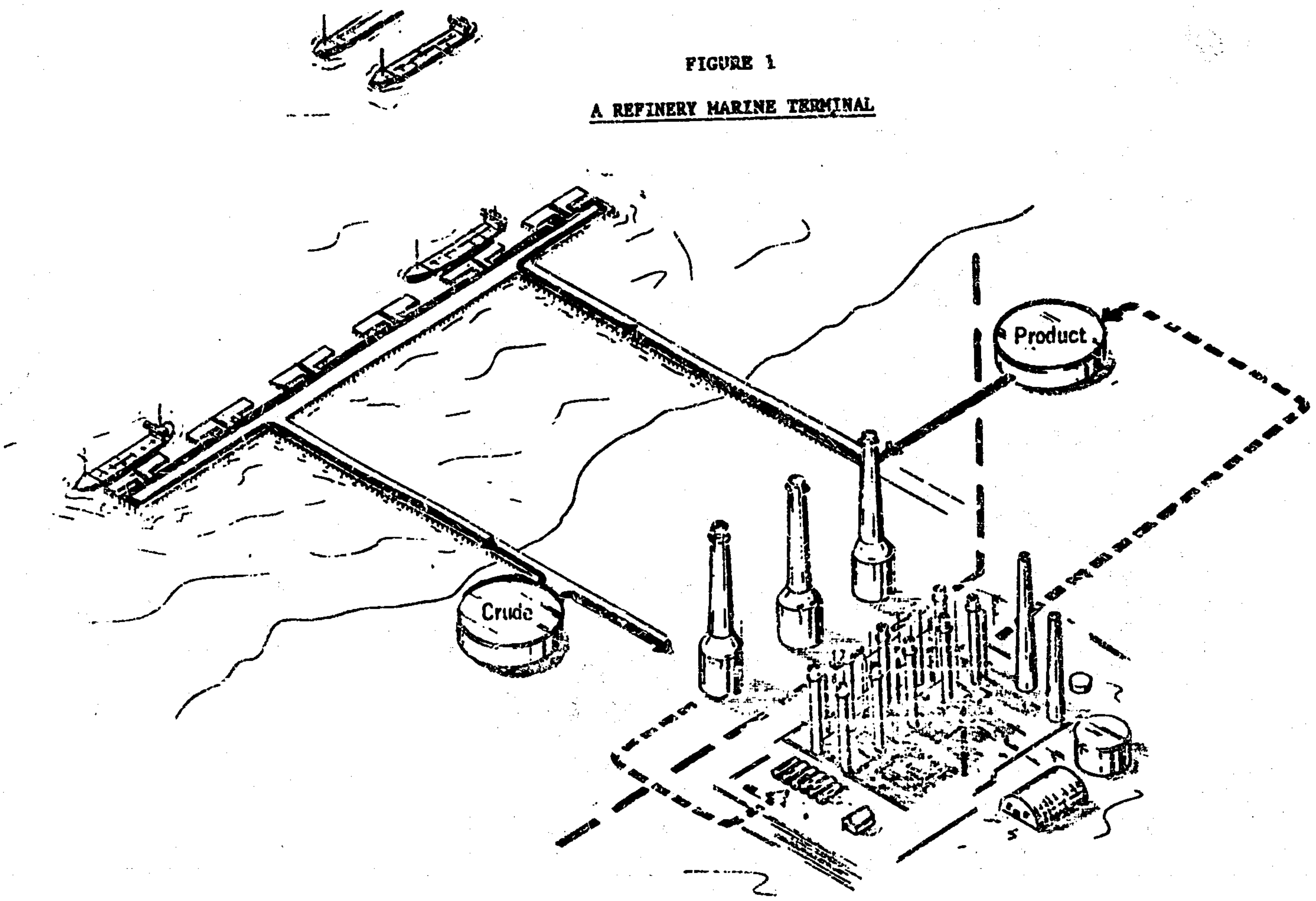
I. THE MARINE TERMINAL INVESTMENT PROBLEM

The oil tanker is a fundamental means of transportation in the petroleum industry. It follows that marine terminals, where tankers can be loaded or unloaded, are fundamental to a transportation system based on tankers. A refinery marine terminal is illustrated in Figure 1. The ability of an oil company to utilize its tanker fleet is dependent upon that firm's configuration of marine terminals. Anytime that a tanker is delayed in port, its capacity is lost to the transportation system. Accordingly, additional tankers must be brought or chartered to compensate for such delays. In planning facilities for a marine transportation system, it is necessary to estimate and plan for the time lost to port delays -- as well as to eliminate as much of these delays as is economical.

This problem may fall to the manager responsible for the overall transportation system

FIGURE 1

A REFINERY MARINE TERMINAL



or to the manager of a particular terminal in the system. Several kinds of investments can affect the service of a marine terminal. An increase in the size or number of tanks can reduce delays due to insufficient available capacity to unload the ship. Additional berths can permit the servicing of more ships at one time. On the other hand, one might achieve the same results by increasing the flexibility of one or more existing berths. In addition, it is possible that improvements can be affected by changing certain operating procedures, such as the rules for assigning ships to berths. More often than not, delays can be reduced most effectively by implementing some combination of the above alternatives.

The evaluation of these alternatives is quite complex. One must analyze the effect of different terminal facilities under various modes of operation. Furthermore, ships arrive with varying degrees of randomness, and service time is highly dependent upon the status of the system at the time of arrival. If ships arrived in regular intervals, then the system could safely be designed to process the average number of ships in port. Generally, however, the ship arrivals are "bunched", and the number of ships in port <u>at any point in time</u> may be several times the average. The effect of bunched ships competing for the same facilities can often be the most important factor in ship processing time, and this factor cannot be evaluated using average value analysis.

Proper analysis must take into account the complexities of current operations, but it must also anticipate the changes which will influence their operation in the future. As in any industry, factors such as processing volumes are bound to change. In addition, however, the oil industry is in the midst of altering the entire complexion of its marine transportation. For instance, many of the new tankers are extremely large. These ships bring more cargo into port at one time. They may take up more than one berth at a terminal. Voyages of these tankers are often restricted to specific routes, with smaller tankers transhipping cargo from large terminals t smaller terminals. New modes of operation are evolving in order to deal with the interaction of these new factors. As a result of all this change, it has become increasingly difficult to draw conclusions from intuition and past experience.

II. SIMULATION AS A TOOL FOR ANALYSIS

It should be evident that simulation is particularly appropriate for analyzing the operations of a marine terminal. Simulation has the flexibility to study this complex situation without imposing unreasonable simplifications on the problem statement. By the use of case studies, it is possible to analyze the impact of changes in facilities or operating procedures. Simulation can represent irregular and uncertain phenomena in the system. Furthermore, additional case studies may be used to measure the sensitivity of the system to changes in the projected operating environment, including such factors as demand, weather, and unscheduled maintenance.

Any marine terminal simulation model must realistically approximate two complex phenomena -- the arrival of ships and the servicing of these ships once they are in port. In order to simulate the arrival of ships, one must account for the influence of variability in the ship arrival patterns. The servicing of ships is best simulated by a detailed representation of the actual decision process which governs the operation of the terminal.

This kind of model requires a detailed set of input, describing vessel characteristics, product and crude demands, berth capacities and flexibilities, environmental conditions (such as weather and tides), and operating rules (governing berth and ship assignment). The output reports from a case can include both summary and detailed information on delays and inventory levels. In addition, the model can calculate the cost associated with the delays.

Delay costs are derived from the cost of chartering lost tanker capacity at projected market rates. As in any investment study, the terminal manager must evaluate any proposed investments against the related savings in projected costs.

III. DESCRIPTION OF A GENERAL MARINE TERMINAL SIMULATION MODEL

In the early nineteen sixties several models were successfully developed and applied to marine terminals in such places as Italy and Libya. Although each application more than paid for itself, steps were taken to reduce the time and money required to complete a particular simulation study.

Accordingly in 1967, a general model was developed with the specific design feature that it be easily tailored to most refinery marine terminals in the Exxon Corporation circuit. Existing technology was consolidated in this one model, and improvements in technology since then have also been incorporated in the model.

The model will be described from two points of view: the problem characteristics modeled, and additional technical features of the program.

A. Problem Features

1. Tanker arrivals at the terminal reflect a mix of planning and variability. The total number of arrivals each year is kept consistent with the total amount of crude or finished product processed during the year. The planned arrival time for each tanker is ideal from an inventory control standpoint, which reflects the actual tanker scheduling procedures. That arrival time, however, is subject to variation by inputting either a histogram or a standard deviation to the normal distribution.
2. If storms can close all or part of a terminal, the model will generate a pattern of storms of length and severity corresponding to the input provided by the user.
3. As each vessel arrives at the terminal, it is placed in the queue. The queue is ordered on a first - come, first - served basis, unless the user has elected a special priority basis. The special priority option groups the vessels according to priority class, then according to size within each priority class.
4. The complex berthing rules are summarized as follows:
    a. The berths are examined in preferential order, which is generally from least to most flexible. If a berth is free, and if weather permits, each ship in the queue is examined in turn until a match is obtained.

    b. The berth must be able to handle the size and cargo of the ship under consideration, and the lines required to load or unload the ship must be available at the berth.

    c. If the ship is to unload cargo, the ship will not be berthed until there is enough space in the tanks to accept the ship's entire contents.

d. A berth might be "reserved" for an incoming large tanker. This would prevent a smaller ship from berthing if that would delay the large tanker.

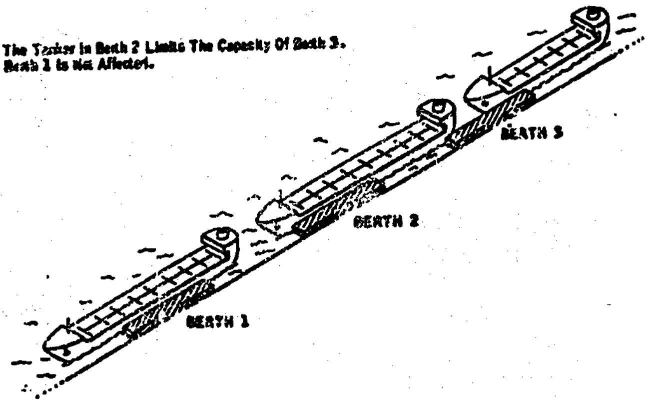
5. A ship which has qualified for berthing will go through the time delay required to maneuver into the berth and await line assignment, to complete the loading or unloading of its cargo, to release its lines, and to maneuver out of the berth. These components of port time are constant, provided facilities are available.

6. If the assignment of a particular ship to a particular berth should interfere with the capacity of a nearby berth, the capacity of the nearby berth will be adjusted during the time that the first berth is so occupied. This phenomenon is illustrated in Figure 2, where the large ship in Berth 2 limits the size of the ship which can go to Berth 3.

7. Crude inventories can be drawn down on a continuous basis. In the case of crude runouts, the crude drawdown rate is later increased until the loss is made up. Some tanks may be restricted to holding one crude only, whereas others may be available for use by several crudes.

8. Produce inventories are monitored. It is assumed that products are produced at a constant rate, while export or import operations are carried out by the vessels. The model makes no attempt to relate crude operations to product operations, or for that matter to relate the operations of different products to those of each other. To do so would require modeling the detailed refinery operations, which is beyond the scope of this model.

Figure 2


The Tanker In Berth 2 Limits The Capacity Of Berth 3.
Berth 1 Is Not Affected.

B. <u>Additional Technical Features</u>

This section describes certain technical features not specifically related to the problem structure of the model.

1. The model is coded in highly modular fashion. Input operations are in one location, output in another. There is a separate routine for each operation in the simulator (such as queuing, line connection, and berth departures). Consequently, it is very easy to isolate those portions of the program which require alteration in a particular study.

2. The model is programmed in FORTRAN. FORTRAN was selected because of its computing speed, its wide use throughout the Exxon Corporation affiliates, and because it lends itself very well to a highly modular structure.

3. The model contains an option to generate random numbers for ship arrivals and storm statistics using a "variance reduction" procedure known as "random sequence sampling". The procedure selects without replacement from a predesignated set of numbers, but in random order. The mean of resulting statistics (e.g., delays, turnaround time) is unaffected, but the variance is substantially reduced. In most cases, the mean of a statistic is the measure desired, and equilibrium conditions can be reached much sooner using this option, which thereby reduces computer time per case.

4. The model accepts input data in "free form". This means that data is identified by the use of keywords, rather than by card number or card column. As an example,

   PRTANKERS BOUNTY SIZE 80 NUMPRODUCTS 2

   would be interpreted to indicate that the product tanker BOUNTY has a draft size of 80 and carries 2 products. This input system was included in 1971, and since then it has proven far more viable than the former system based on card columns. The new method is also more amenable to the use of remote teletype or cathode ray tube terminals.

5. The model tailors the dimensions of nearly all vectors and arrays to meet the specifications of each case. This recent feature has eliminated the substantial re-dimensioning (and accompanied debugging) that used to be a part of every study. It has also eliminated the wasteful tendency to over-estimate array size in order to avoid later redimensioning.

In the future, additional features will be added according to the two processes which have brought about modifications and extensions to date: technological advances and refinements developed for particular studies.

IV. A CASE STUDY EXAMPLE

This section makes use of an example to outline the steps essential to virtually any application of the general marine terminal simulation model. This particular example is based on an actual study, done for one of the Exxon Corporation refineries in the summer of 1971.

A. Study Objectives and Manning Requirements

The specific objective of the study was to evaluate alternative proposals for pier expansion and also for additional crude oil storage tanks. A broader objective was to provide the refinery staff with a model that could be used for similar studies at any future date. Accordingly, the study was manned jointly by refinery personnel familiar with computer programming and by a member of the central OR group. The refinery personnel provided the expertise in the local terminal operations, and the OR man provided the expertise in the general model. By the end of the study, the refinery staff was completely capable of using the adapted model without further outside assistance.

B. Modeling Considerations

One of the first activities in setting up a study schedule was the description of the physical problem in modeling terms. This description could then be compared to the features of the existing model in order to identify the modifications required to represent the refinery's terminal operations.

The basic problem structure was well-suited to the application of the model. Vessels arrived at the terminal, based on an ideal inventory control strategy, but subject to random variations. Upon arrival, a vessel would be berthed immediately, provided sufficient empty storage existed to receive the ship's entire cargo, and provided there were an empty berth equipped to receive the ship. Otherwise, the ship would be placed in a queue until those conditions were met. In addition, subsequent arrivals of higher-priority vessels could further delay the servicing of a ship. Records were kept on each ship's total turnaround time in port, together with a breakdown on the various sources of ship delay.

Characteristic of other applications of this model, some aspects of this specific terminal's operation had not been anticipated in the model's design. Accordingly, portions of the logic had to be changed to complete the representation of the terminal. It was here that the modularity of the model proved especially useful. Because of the ease of changing one portion of the model without affecting others, substantial logic changes were incorporated by altering about 300 out of 7500 source statements in 12 of 51 subroutines. The major changes are summarized here to illustrate the kinds of factors that hinder complete generality in this type of model.

1. Transshipment vessels discharged one grade of crude oil and picked up another grade for delivery at another terminal. This required coordinated scheduling between all vessels for the two crudes. Normally, the vessels for each crude would be scheduled independently.
2. A scheduled maintenance period closed the terminal for twelve hours each week. This scheduled closure could occur only after all berths were empty, and consequently it imposed a restriction against berthing a ship too soon before maintenance began.

3. The queuing rules were more complex than those originally programmed, in that they allowed for increasing a vessel's priority if it had been delayed beyond a specified period.
4. The interaction of berth capacities (as illustrated in Figure 2) was also more complex than in previous applications of the model. Several berths were so close together that the berthing of a large tanker in one of them restricted the capacities of the rest of them.

C. Validation of the Revised Model

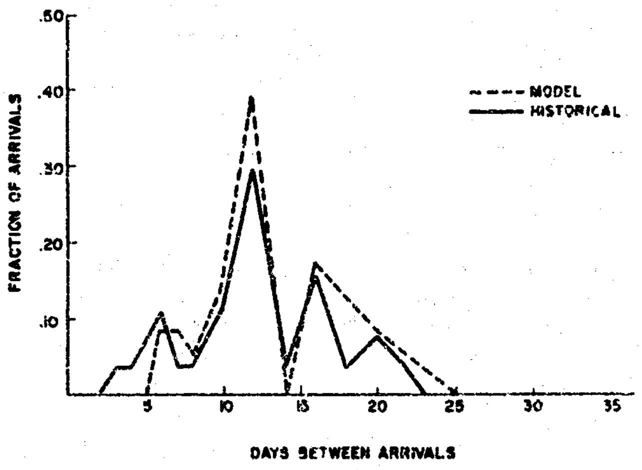
At the same time that the modeling changes were being specified and coded, data was being prepared for a validation case, taken from the refinery's 1969 records. Validation of the model consisted of checking model performance against actual results, and also of establishing how long the model should be run to represent system performance. Both facets of validation were prerequisites to using the model for case studies of future performance.

The most time-consuming part of validation consisted of comparing model statistics with historical results. As a first step, the model demonstrated that it could generate vessel arrival patterns representative of those during the 1969 test period. Figure 3 shows one comparison between the historical distribution of interarrival times and the corresponding distribution generated by the model. Secondly, once the arrival patterns had been validated, the model was also able to produce realistic operational statistics for berth occupancy, delays, and maintenance.

In addition to validating the model against past performance, it was necessary to determine the length of simulated time required to achieve equilibrium. This was established by comparing the results of a particular case run several times using ship arrival patterns generated from different sequences of random numbers. In this instance, the results become stable after four years of simulated time. This required approximately seven minutes of 360/65 CPU time per case.

FIGURE 3

HISTORICAL AND SIMULATED INTERARRIVAL DISTRIBUTIONS FOR CRUDE A TANKERS

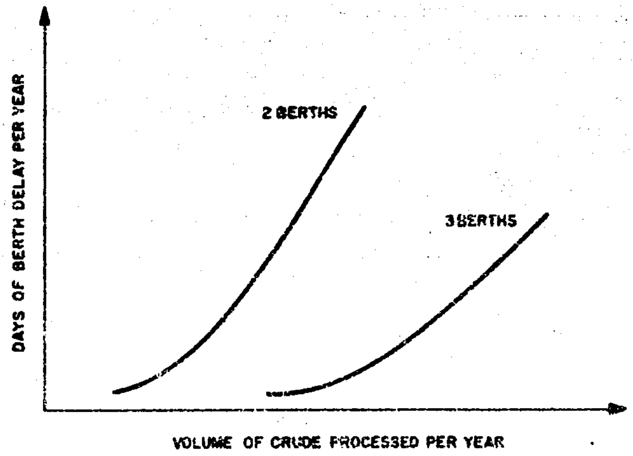


D. Case Studies

Case studies and analyses were completed following the validation of the model. Figure 4 illustrates one set of relationships established by running case studies with the model. This particular graph relates the volume of crude processed per year (which dictates the volume of ship traffic) to the expected time spent waiting for berths. Curves have been plotted for configurations of two and three berths. The decision to build the third berth would, of course, be justified when the volume reached a level such that the (time-adjusted) difference in delay costs exceeded the investment outlay. Case studies would also be used to derive similar relationships for crude storage tanks or other terminal facilities.

FIGURE 4

EFFECT OF REFINERY VOLUME ON BERTH DELAYS



E. Study Duration

Model re-design, revision, validation, and the running of initial cases were carried out in nine weeks. At the end of that time, the development was complete, and the refinery staff were completely indoctrinated in the application of the model. No further outside support was necessary either to run additional cases or even to modify the model if the need arose.

V. CONCLUDING COMMENTS

For the past decade, simulation has proven to be an effective tool for the study of marine terminal facilities. The general model has provided numerous studies with a framework for problem identification, solution, and analysis. There is every expectation that marine terminal simulation will continue to be a widely accepted technique throughout the affiliates of Exxon Corporation.