SIMULATION OF INDUSTRIAL BULK CARGO OCEAN SHIPPING

by

Edward Graham Preston

A Thesis Submitted to the Faculty of the

DEPARTMENT OF SYSTEMS ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 6 6

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Edward G. Preston

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Lucien Duckstein

LUCIEN DUCKSTEIN
Professor of
Systems Engineering

2 June 1966

Date

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. Lucien Duckstein for his advise, helpful suggestions, and moral support and encouragement during the preparation of this thesis.

He is also indebted to Dr. Jerry L. Sanders for his helpful discussion and criticisms throughout the past year.

Most of all he wishes to thank his wife, Kay, for her patient understanding and confidence and for her quick and competent typing of the draft copies of this thesis.

Mr. George Henry and Mr. Pieter Tuchscherer of Marcona Corporation, San Francisco, have been most helpful in providing prompt and detailed information and answers to many questions over the past year.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF FIGURES AND TABLES

ABSTRACT

The problem of scheduling an industrial fleet moving iron ore to world-wide consumers is examined with the aim of applying computer simulation in the study of such problems. The requirements and structure of such a simulation program are presented. A scheduling routine, written to be a part of the complete simulation, is described. Finally, several possible applications are presented for the use of simulation in studying industrial, ore shipment scheduling.

Chapter One

THE LARGER PROBLEM

Introduction

For many years the merchant shipping industries of the United States and many other countries have been plagued by serious and growing problems. Spiraling wages and operating costs and greatly increased competition in the world freight and cargo market have left many of the world's merchant fleets dependent on subsidies from their home governments. The shipping industry has fallen far behind the technology of the age and hence, has been unable to rescue itself from the dangers of financial stagnation. Concerned about the state of the country's merchant fleet the federal government, acting through the Maritime Administration, has taken the lead in research necessary to modernize the maritime services of the country. In the past ten years, also, several of the nation's leading shippers have been spurred by rising cost and competition into renewed efforts to modernize their operations. As a result, hopeful new ideas have emerged across the full range of maritime operations from specialized ship designs to labor relations, and from improved scheduling to automation of paper handing.

One of the tools which has recently been applied in the study of the problems of maritime shipping is computer simulation. Although a great deal of analysis has been directed towards simplified and reduced forms of transportation problems the great complexity of the problems of ocean transport has, so far, defied analytic description in any general, closed form. The concept of a magic computer program to optimize ocean transport has been termed a "popular fallacy" (Datz el al., 1964). Analytic models have thus far found only limited applications in the industry and managers have been left with operating policies and decision-making tools which were in use when merchant fleets were powered by sail (Roth, 1957). In an effort to provide managers with a practical decision making tool and, at the same time, to develop a tool of use in studying the complexities of shipping problems several current attempts are being made to simulate shipping operations on digital computers (Weldon, 1959; Datz et al., 1964).

The simulation effort described by Weldon (1959) is being conducted by the Matson Navigation Company. The simulation described by Datz et al, (1964) is the Maritime Administration Fleet Operations Simulation. Both of these simulation programs are specifically designed to study general cargo service in scheduled liner operation. They cannot be used in tramp or industrial fleet operation.

Industrial and tramp fleet operation both vary significantly from liner operation. A liner service is defined to be one which operates ships according to fixed, announced schedules and handles general cargo at preset freight rates. Its ships depart on schedule whether the holds are full or not. A tramp service sends its ships on a nonscheduled basis to any port where cargo is available and usually handles only ship load quantities. Each individual cargo contract is the product of separate negotiations to determine freight rates, sailing dates, and other specifics of the agreement. Tramp operation is limited to providing common carrier service. Industrial fleet operations are similar to tramp operations except that the ships are owned by either the producer or the consumer of the cargo carried. The primary purpose of the ships is to haul only the cargo of the owner and hence the service is not considered to be common carrier.

Purpose and Organization of This Thesis

The primary purpose of this thesis is to explore and describe the simulation of an industrial fleet operation and to provide basis and direction for further work in the study of industrial shipping problems. Although the present study concerns only an industrial fleet operation it has some applicability to actual scheduling of ships in a tramp operation. The complete working simulation of the specific industrial shipping operation studied will be referred to as the Industrial Fleet Simulation. Only a small portion of the final simulation has been programmed and run on a digital computer. This portion will be referred to as the Scheduling Routine.

Chapter One introduces the industrial shipping operation which is to be the basis for the entire work. The ship scheduling problem is defined in terms of the cargoes and the available fleet. The corporate structure within which the shipping operation exists is described in order to properly frame the ship scheduling problem in the decision making structure of a particular corporation.

Chapter Two describes the ship scheduling problem in more detail. It analyzes the variables and parameters of the problem and discusses the relationships which exist between them in order to provide a base of information from which to understand the simulation effort.

In Chapter Three the Industrial Fleet Simulation is described as it is envisioned in its mature, fully developed form. A more detailed description is given of the first version of the Scheduling Routine. The general structure of the routine is described without inclusion of the many programming details.

Chapter Four presents extensions and further development work which will be necessary to complete the Industrial Fleet Simulation. It describes both immediate improvements that may be made in the next version of the Scheduling Routine and work remaining to be done in completing the whole simulation.

Chapter Five deals with application of the simulation in the study of practical problems. It discusses the problem of evaluating the realism of the simulation; it describes and presents examples of the general types of problems which may be studied with the simulation; and it draws conclusions about the practical use of simulation as an approach to industrial ship scheduling.

Description of the Ore Production and Marketing Operation

General

The remainder of this chapter is devoted to description of the shipping service to be simulated. The organization and operation to be described are based on those of the Marcona Corporation whose headquarters are in San Francisco. Marcona Corporation, under a recent consolidation, now manages the Marcona Mining Company and Cia. San Juan. The mining company operates large iron mines in Peru, while Cia. San Juan is a sales and shipping company for distribution of the iron ore produced by the mining company. The shipping operation of Marcona Corporation is therefore classified as an industrial shipping service since the owner of the ships is also the producer of the cargo. A number of liberties have been taken in altering the operation to be simulated. These alterations have been for two reasons: the real operation was simplified to facilitate the first attempt at simulation and, in some cases, detailed, accurate data has not yet been obtained from Marcona Corporation, necessitating the use of hypothetical data and extrapolated data. For the remainder of this thesis then, the term "The Corporation" will refer to a somewhat hypothetical company similar in operation to Marcona Corporation, owning a fleet of ships and operating a mining complex which produces iron ore to be transported by those ships.

The Cargo

The iron ore mined in Peru by The Corporation is sold to consumers in Japan, Eastern United States and Europe. Since the primary task of the shipping fleet is to transport The Corporation's iron ore, the sailing pattern remains fairly stable between these areas. In order to relieve the expense of returning ships in ballast to Peru, The Corporation makes contracts for back haul cargo to complement the iron ore trips. These back haul cargoes consist primarily of crude oil from the Persian Gulf and Indonesia (Sumatra) to be shipped to California, coal from the eastern coast of the United States to Japan, and freight from the United States or Europe to Peru.

The Fleet

The shipping fleet consists of seven owned ships, a number of "time chartered" vessels which are scheduled as if owned, and a number of F. I. O. (Free In and Out) vessels which are chartered on either a one way or bulk tonnage basis. In 1966 and 1967 two more owned vessels of approximately 61,000 tons and 90,000 tons deadweight will be added to the fleet. The present ships range in cargo capacity from 30,000 to 70,000 tons.

The total ore sales of The Corporation greatly exceed the carrying capabilities of the owned and time chartered vessels so a number of F. I. O. charters are required each year to meet sales commitments. Negotiations for these contracts are handled by a ship brokerage firm which is affiliated with The Corporation. The F. I. O. charters are frequently made for ships making return trips from previous assignments and hence can often be obtained at very favorable rates. Evaluating the desirability of a specific F. I. O. charter is a difficult task because such charters often free owned or time chartered ships for other uses and the ultimate effect in the future of taking a charter now becomes difficult to determine without a large number of calculations.

Vessel Scheduling Restrictions

The ultimate purpose of vessel scheduling is to move a given quantity of ore to specified destinations for the lowest overall cost. However, the scheduling is severely restricted by a number of constraints which must be satisfied in order to provide feasible and practical results. These constraints result from:

1) Destination port draft limitations
2) Panama Canal passage limitations
3) Vessel hire commitments (back haul cargo)
4) Ore sales contract requirements
5) Stock pile and production of ore

(Henry, 1965).

Further details of these five restrictions are described below.

1. Draft limitations at delivery ports may prohibit some ships from entering certain ports fully loaded. This problem may be solved in several ways. Whenever possible, ships may be scheduled only to ports which they can enter fully loaded. Beyond this, multiple port discharges or discharging excess cargo into lighters can be arranged to lighten the ships before they enter restrictive harbors. The latter two solutions would necessitate adjustments in the freight rates for the trip to cover the additional costs involved.

2. Panama Canal restrictions are, perhaps, more difficult than destination port restrictions since they place an absolute limit on the tonnage of ships for trips requiring canal passage. Seventy thousand ton ships are

severely restricted and the use of such ships on trips from Peru to Europe or Eastern United States is impractical. Draft limitations of the canal limit the payload of all but the smallest ships. Generally, the larger the ship the less practical it is to operate it through the Panama Canal.

3. Ships are made available for use through various contractual arrangements as earlier described. The contractual arrangements may place restrictions on the use of the ships in terms of the ports they will be permitted to visit or the cargoes they may haul. In making up schedules, owned and time chartered ships should be used first since the company "pays" for these ships whether they are in use or not. Once these ships are fully utilized F. I. O. charters must be arranged at the best rates available to handle other cargo still unshipped.

4. Iron ore is supplied to customers in a number of grades and specifications. Since at all times the ships must make trips fully loaded for economy, several ore "parcels" may be transported in different holds of the same ship. Generally customers require an evenly distributed delivery pattern within the contractual period; occasionally specific delivery dates or weeks are required.

5. The combined production and stockpiling capacities of the mining complex and port facilities in Peru set bounds on the shipping tonnage to be loaded at Peru in a given period of time. If the lower bounds are violated the

mine production may have to be curtailed because of the lack of storage capacity. If the upper bounds are exceeded stock piles will be depleted and ships may encounter excessive delays waiting for available ore. The end result, then, of efficient scheduling will be a balance between sales demand, shipping availability and mine and port production and stockpile planning.

The Larger Problem

It is necessary to make some assumptions about the profit motives and structure of the companies involved in the operation. Assume that the corporate ownership structure is as shown in Figure 1. The Parent Corporate Structure acts only as owner of the lower companies and is not in a position to influence their operations by any manipulation of its own operations. Profits from the combined operation of The Corporation and the companies it manages are the prime concern of the Parent Corporate Structure. The Corporation owns and manages both the Mining Company and the Ore Sales Company. The Ore Sales Company, in turn, owns and supervises the management of the Shipping Company. The entire output of the Mining Company is purchased by the Ore Sales Company. The Shipping Company provides all of the shipping necessary to satisfy the sales of the Ore Sales Company, either through use of owned or leased ships or through use of chartered ships. All charters are arranged by the Ship

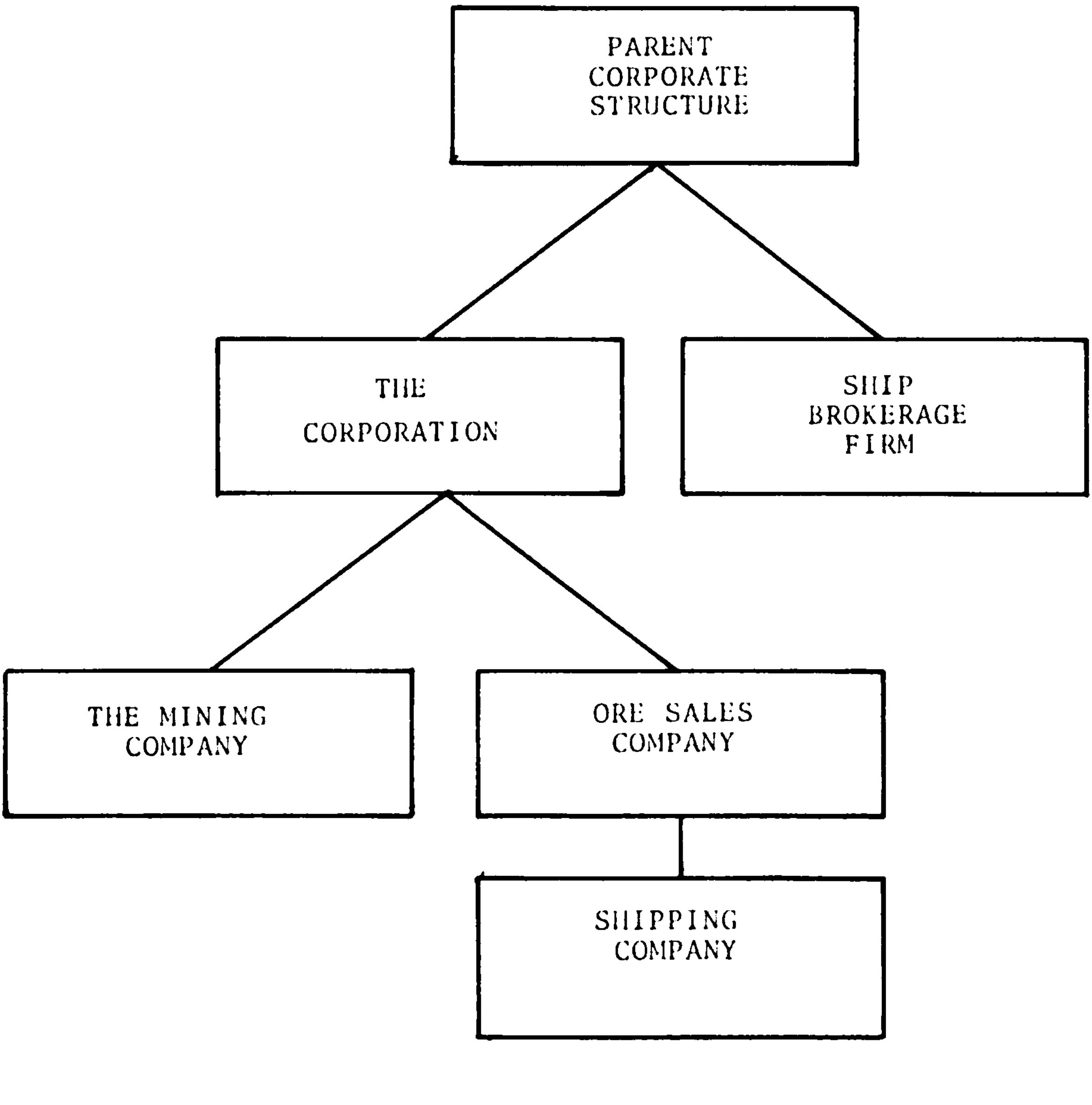

Figure 1. Corporate Structure

Brokerage Company. All contact with iron ore consumers is made through the Ore Sales Company, while all contacts with the world shipping industry are made through the Ship Brokerage Company. The information flow for the complete ore production-marketing operation can then be described as in Figure 2.

The four companies shown in Figure 2 may be considered to be a complete system interacting with customers and competitors only through the information links shown. The information links to the ore customers and to the world shipping industry represent both the input and the output terminals to the system. A great deal must be learned however, before the system can be defined mathematically in terms of input functions, state sets, transfer functions, and the change of state or next state functions. All of these will be very complex and it may, in fact, be true that it will not be possible to model the entire mining-sales-shipping operation as a mathematical system.

Since this system is entirely owned by the Parent Corporate Structure which is interested only in total financial returns, each company in the system must be motivated by the common interest. In short, each company strives to maximize the total financial return of the entire production, marketing, shipping operation. This maximization effort requires a continuous "conversation" between the information processing and control elements

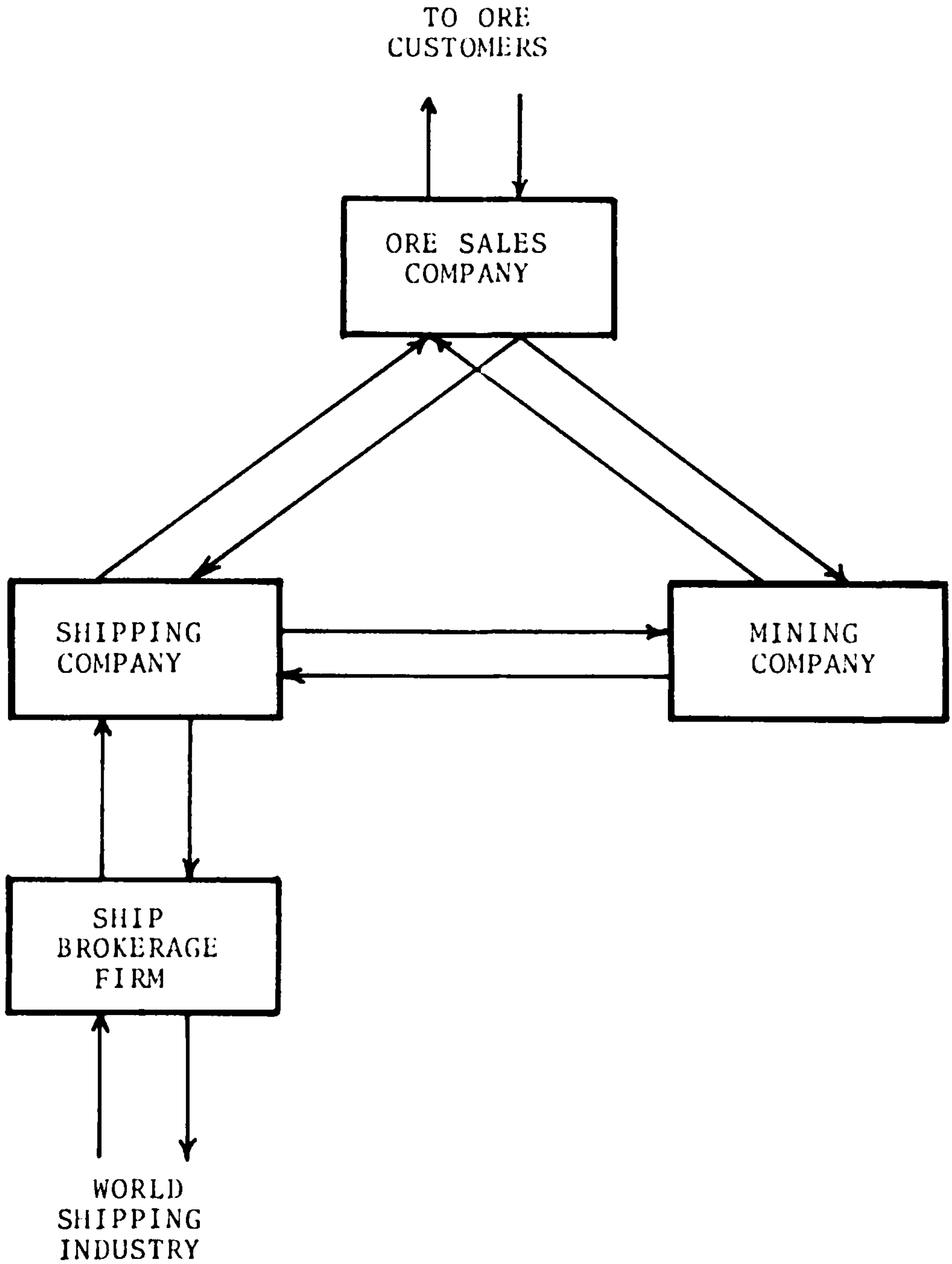

Figure 2. Corporate Communication

of each of the four companies. An example of the type of information which would flow over the interconnections is as follows: consider the output of the Shipping Company which is fed as input to the Mining Company (Figure 2.). A message might read, "We would like to follow a shipping schedule that, in two months, would result in a two week period in which no ships will arrive in Peru, followed by a week in which six ships will arrive to pick up 250,000 tons of ore. What effects will this have at your facilities?" The reply might be, "The two week period of no arrivals is ideal since it will give us a chance to replenish low stockpiles, however, we have scheduled construction in the port for the following week which will limit loading ability to three ships and/or 120,000 tons. Advancing completion date of the construction can be arranged only with the following consequences . . .".

Summary

In Figure 2 the input-output relations of each of the "black boxes" are themselves highly complex. Analysis, or even description in closed form, of the entire control process is a very formidable problem. The discussion in the following chapters and the simulation which will be described are concerned only with the operations of the Shipping Company. The intention is to gain some insight into the problem of ship scheduling and to develop a tool, namely a simulation routine, which will be useful in studying the problem and in assisting managers who must make decisions "today". The present chapter has placed this problem in its larger environment.

Chapter Two

ANALYSIS OF THE SHIPPING PROBLEM

Introduction and Purpose

Before proceeding with the simulation of the shipping operation it is necessary to analyse the problem to determine the pertinent variables and their relationship to one another, and to determine which variables can be manipulated, which are really parameters, and which will be useful in determining the "goodness" of a schedule. It is the purpose of Chapter Two to perform this analysis, to discuss the problems encountered in the use of "optimizing" models, and to select the variables and parameters which will be important in simulating the shipping operation.

Analysis of Variables and Parameters

The Problem and Solutions

It will be useful to look first at the problem statement in order to determine what constitutes a solution to the problem. In short, the problem is: Given a set of owned and time chartered ships, a set of ships available for F. I. O. charter, and a set of cargo requirements for a fixed period of time, find a set of ships to haul the cargo and a schedule covering the entire problem time period for each ship in the set; the contraints of customer demands and ore availability must be satisfied and the return or benefit to the company should be "optimum" according to some yet to be stated criterion. The problem as here stated is an abstraction and hence, not completely satisfactory. Both the cargo requirements and the ore availability are, in reality, not fixed but admit to some flexibility and, at time, sharp changes. It is precisely this flexibility and the problems of stating definitively the optimality criterion which create the need for the "conversation" between the companies involved, as mentioned in Chapter One. In examining the abstracted problem it is important to keep in mind that the purpose of the present work is to ultimately deal with the real problem.

A solution to the abstracted problem would then consist of a set of ships and, for each ship, a set of sailing (or arrival) dates, destinations, and cargoes carried which would define the utilization of all ships during the problem period.

Manipulated Variables

In the present problem, as in a linear programming problem, the variables eligible for inclusion in the solution are the variables which are manipulated in order to arrive at "optimality". Defining the utilization of a ship for a single trip essentially requires three pieces of information: where the ship is going, when it is to depart (or arrive), and what it is to carry. A solution covering the entire problem period would include a sequence of sailings and hence a sequence of trips, dates, and cargoes for each ship. In the problem statement above a cargo requirement implies tonnage and a port of origin and a destination. Hence, we can determine both the trip and the cargo by stating the cargo commitment and the number of tons carried against that commitment. A solution to the entire problem, then, will consist of the variables C(i,j), D(i,j) and T(i,j), i=1,2,...,m; j=1,2,...,n. The subscript i corresponds to a ship number with m ships available and j indicates that this is the jth task of a maximum of n tasks performed by ship i. C(i,j) will be equal to an integer indicating a cargo parcel, D(i,j) will represent an arrival date and T(i,j) will be the number of tons carried from cargo parcel C(i,j). The variables C(i,j), D(i,j), and T(i,j) are the manipulated variables of the problem. From them and the known parameters of the ships, cargoes and ports all other quantities may be calculated.

Parameters

The word parameter as used here refers to all those quantitative aspects of the problem that cannot be freely manipulated and which have relatively fixed or predetermined values for any given situation. The parameters of this problem could be generally subdivided into three categories: ship parameters, cargo parameters, and trip parameters. Since the parameters associated with a given trip, for example travel time, also depend on which ship is making the trip, the trip parameters will be grouped with the ship parameters. As the discussion proceeds it will be necessary to present further details of the operation which were not presented in Chapter One.

Ship Parameter. The most obvious, and indeed the most important, parameters associated with a ship are those which effect transportation time, cargo capacity, and operating costs. In liner operations such as those discussed by Weldon (1959) and Datz, et al. (1964) these parameters are extremely complex and variable; however, in the industrial shipping operation under consideration, a more detailed examination of the operation will show that the problem parameters can be greatly simplified.

Transportation time is basically composed of loading time, travel time, and discharge time. Loading time and discharge time are functions of ship capacity, type of cargo, and the port facilities available. In this problem a given port will handle only one type of cargo. For example, at Peru only iron ore is loaded; at Sumatra only oil is loaded. It is then possible, given a ship and a particular port, to predict with a high degree of accuracy the loading or discharge time. Experience has also proven that operating ships at a standard cruising speed provides the most economical operation. This has allowed The Shipping Company to establish tables of standard voyage times for all of their ships. These tables give accurate estimates of the time in days required for each ship to make the various voyages which may be assigned to it. Significant departures from these voyage times occur only with such infrequent events as disasters at sea, typhoons, acts of war, etc. Since the scope of this study is not sufficiently broad to cover such infrequent events the travel times will be considered to be essentially constant. The transportation time, then, for a given cargo will be assumed to be a fixed parameter depending on the ship to be used and the trip (ports) involved.

There are several other less predicable time factors involved in shipping which are here combined under one "delay" term. This includes delays in entering or leaving ports caused by tidal activity, possible waiting time for loading or unloading facilities in busy ports, and delays for provisioning, bunkering, and minor repairs needed before the ship can sail again. The predictability of these delays depends on both the ship and the particular port. No factual information on such delays has yet been obtained by this author. For present purposes such delays will be handled by simply adding an average delay, as a constant term, to the travel time for trips beginning at the port where the delays occur. It should be noted that further study of the effect of such delays on ship scheduling is needed.

Cargo capacity is primarily a function of the size and construction of a ship and the density of the cargo. However, it is further restricted by draft limitations of ports and of the Panama Canal. It is a relatively simple matter to determine for each ship the maximum cargo capacity for each possible trip. These capacities will be expressed in dead-weight tons.

Cost parameters associated with a ship's operation are more complex than are the previously mentioned parameters. The costs of ocean transport may be divided into the following categories: operating costs on the high seas, port service costs, and cargo handling costs. Calculation of costs depends on the contractual arrangement under which the ship is being used. The fact that ships are used under several different contractual plans often greatly complicates comparisons in cost parameters.

For ships owned by The Shipping Company all costs of ship operation must be calculated. For operating on the high seas these costs include fuel consumption, general operating supplies, crew food and provisions, crew wages, ship insurance, amortized capital cost of the ship, maintenance costs and Suez and Panama Canal tolls. Costs connected with cargo handling include fees for use of loading or unloading equipment, stevedoring, wharfage, dockage, cargo insurance, dunnage, cleaning of holds and cargo tanks, and lighterage. Port service costs cover administrative fees, launch service, repair services, bunkering, etc. (McDowell and Gibbs, 1954). Published documents and records of The Shipping Company contain sufficient information to accurately calculate all of these costs for each owned ship and each trip. Again this problem is simplified by the fact that, for any given trip, only one type of cargo need be considered.

For ships chartered on a time, bulk tonnage, or F. I. O. basis some of the above costs are born by the ship owner and some by the charterer as specified by the charter party (McDowell and Gibbs, 1954). Although these differences complicate the computations, the total cost to The Shipping Company of shipping a ship-load of cargo between two ports on a chartered vessel can still be calculated.

The simplest cost parameter to use, then, is a total cost calculated for each ship making each possible trip. This total cost will include operating costs on the high seas, cargo handling costs, and port service costs at either the port of origin or the destination port, but not both. It is reasonable to use this total cost figure in determining the consequences of ship scheduling because the operator of the ships and the owner of the cargo are one in the same and the associated expenses ultimately come out of the same pocket.

There are also costs associated with delays such as those included in the delay term discussed in the preceding section on time parameters. These delay costs represent the cost to the owner or charterer of a ship for holding that ship idle in port. They correspond to the "demurrage" cost used in tramp ship operation. Delay costs are based on the operating cost on the high seas, minus fuel costs, plus additional port service costs resulting from additional time spent in port. Again, in the case of chartered ships, responsibility for delay costs must be layed out in the charter party. Since, for the purposes of this study, average delay times were added to total transportation time, delay costs will be added as an average value to the total cost of making a given trip with a given ship. Let this total cost be referred to as K(i,j) where the index i again represents a particular ship and index j represents a particular trip. It should again be noted that further study of derogatory effects on future schedules of such delays is needed. A good, working simulation of the shipping operation will be helpful in such studies.

Cargo Parameters. In the preceding paragraphs several parameters were discussed which were functions of cargo as well as the ship. There are several other parameters which depend only on the cargo. A cargo requirement given in the problem includes a tonnage, a trip determined by the origin and destination ports, and a time period within which the cargo must be delivered. If the cargo requirements are identified by an index r then each requirement will have the following associated parameters: tonnage W(r), trip number P(r), earliest delivery date E(r), latest delivery date L(r).

The tonnage of a given cargo requirement will generally be greater than the capacity of a single small ship; however, this is not always the case. Separate parcels of ore as small as 5,000 tons may be considered. Since the ships vary in size, the parcels cannot be in even ship load amounts, hence at times a ship may carry two or even three parcels on one trip. This means that the solution variables C(i,j) for two or three consecutive values of j may represent only one trip of ship i.

Use of the last two parameters, E(r) and L(r), is a practical necessity yet it leads to a number of disturbing problems. These two parameters may be set by the customer because of his own delivery requirements or they may be set by The Ore Sales Company in order to arrange an evenly distributed sales and production schedule. If these dates are used to establish absolute constraints which must be satisfied in obtaining a feasible solution then many situations will arise in which no feasible solution exists. It is more practical therefore to use these dates in assessing penalty costs for delivering cargo outside the specified period. However, before these costs can be included in a total cost function, management must determine the functional relationship between such penalty costs and the tonnage and number of days by which delivery requirements were missed. To date almost no progress has been made in providing a mathematical basis for evaluating the consequences of late or early deliveries in terms of dollar value.

Further mention will be made in Chapter Three and Chapter Four of the problems associated with the parameters E(r) and L(r). Since the delivery dates are subject to some negotiation between the Ore Sales Company and the customer, they represent another fertile area for further study. In many cases the customer is willing to accept deliveries over a wide period of time. The Ore Sales Company then has considerable freedom to manipulate deliveries to suit shipping and production schedules. Further study in this area, perhaps also with the aid of simulation, should provide results of practical significance to The Corporation.

Criteria for "Goodness" of Schedules

One of the greatest barriers to analytic formulation and solution of the problem is the writing of a realistic cost function which will indicate the true practical value of a solution and, at the same time, will permit the development of an optimizing algorithm.

In a linear programming problem the solution variables generally represent quantities which, in the real problem, are physically independent in time and space.

For example, in a classical Hitchcock transportation problem (Gass, 1964) the solution variable x(i,j) may represent the shipment of x(i,j) number of items from source i to destination j, and this is a physical act, or event, that is independent of the event associated with x(k,l) which is the shipment of x(k,l) items from source k to destination l. It is this physical independence of solution events which permits separate costs of these events to be determined and, hence, permits the writing of a linear cost function. In the present problem, however, variables representing time, place, and amount related to one physical event all appear as solution variables. Hence any realistic and practical cost function will be a non-linear, scalar or vector valued function of the manipulated variables.

A vector valued cost function may be useful for human evaluation of a solution since the human can make subjective judgments about the relative importance of the various components of the vectors. However, in order to mathematically define the "goodness" of a solution in such a manner that one solution can always be determined to be "better than", "worse than", or "equal to" another, it is necessary to define "goodness" as a scalar quantity. To do this, all elements of a solution must be evaluated in terms of a common unit so that they may be combined into a scalar quantity. In general a unit of monetary value is the most convenient such unit. Serious practical problems arise here because it is often difficult or impossible to place a monetary value on some of the factors which managers use to judge the desirability of a solution.

For present purposes it will be assumed that the most important factors in determining the value or utility of a solution are total immediate profit to The Corporation and customer satisfaction. The Corporation knows the total profit that it makes on a ton of ore delivered to each specified port by each specified ship. The total profit per ton made for each trip on which back haul cargo is carried is also known and the total cost of each ballast trip is known for each ship. Assume that customer satisfaction may be adequately described by the penalty clauses which are usually included in ore sales contracts. From these penalty clauses it is possible to specify a monetary penalty for each late delivery of cargo as a function of the number of days late and the number of tons. A cost function to describe the "goodness" of the solution could then be written as follows.

Let the solution variables be C(i,j), D(i,j) and T(i,j), i=1,...,m; j=1,...,n; as described on page 18. In a case where T(i,j)=0, indicating a ballast trip, let C(i,j) actually be the trip number. When T(i,j)≠0, C(i,j) will be the identification number of the cargo requirement for which the parcel is being delivered. The following definitions must be made before the cost function may be written:

1. ϕ = total value of a solution;
2. $C \equiv C(i,j)$ = the cargo requirement number for the jth cargo parcel carried by ship i if the corresponding $T(i,j) \neq 0$;

   $C \equiv C(i,j)$ = ballast trip number, if $T(i,j)=0$;
3. $P(i,j)$ = profit per ton of cargo delivered by ship i for trip j, if trip j is a cargo trip;

   $P(i,j)$ = 0, if trip j is a ballast trip;
4. $B(i,j)$ = total cost of making ballast trip j with ship i, if trip j is a ballast trip;

   $B(i,j)$ = 0, if j is a cargo trip;
5. $J(r)$ = number of the trip associated with cargo requirement r;
6. $T \equiv T(i,j)$ = tonnage of the jth cargo parcel delivered by ship i;
7. $D \equiv D(i,j)$ = delivery date of the jth cargo parcel delivered by ship i;
8. $Q(r)$ = penalty cost per ton per day for late cargo for cargo requirement r;
9. $L(r)$ = late date for cargo requirement r;
10. $E(r)$ = early date for cargo requirement r;
11. $Z(x)$ = 0 if $x \leq 0$;

    = 1 if $x > 0$.

For the jth cargo parcel delivered by ship i the profit per ton is P(i,J(C)). If the jth parcel for ship i has a zero tonnage, T(i,j), indicating a trip in ballast, the cost of that trip is B(i,J(C)).

Penalty costs are incurred only for parcels for which T(i,j)>0 and D-L(C)>0, or when

$$Z(T)\cdot Z(D-L(C))=1$$

Using these facts, the total value, ϕ, of a solution schedule is then:

$$\phi=\sum_{i=1}^{m}\sum_{j=1}^{n}[P(i,J(C))\cdot T-B(i,J(C))$$

$$-Z(T)\cdot Z(D-L(C))\cdot T\cdot[D-L(C)]\cdot Q(C)]$$

Although this function is quite tedious to calculate by hand it can be very easily programmed for calculation on a computer. The function ϕ may be used, then, to compare the value of scheduling solutions obtained by analytic methods or as the result of a simulation program. Other more complicated functions, such as a quadratic function of the number of days late, could be chosen to evaluate schedules but this depends on the willingness of management to state what is important in a shipping schedule and to specify all coefficients and parameters required by the resultant cost function. For present purposes the function ϕ, as defined above is considered adequate.

It should be noted that the function ϕ is really a function of the discrete variables i and j which are defined on only a nominal scale. Hence, such a cost function is not useful for analytic solution of the scheduling problem by such methods as mathematical programming.

Problems of Analytic Optimizing Models

Many of the problems which arise in attempts to optimize shipping schedules with analytic models have already been suggested in the preceding sections. These problems primarily revolve around the difficulties of writing reasonable and realistic cost functions and the difficulty of developing algorithms to manipulate functions of quantities which have only nominal values. There is another aspect of the problem which has not yet been discussed and which adds further complications to the analysis. This is the dynamic nature of the relationships involved. The assignment of a task (cargo requirement) to a ship at one point in time will affect all future assignments of not only that ship but all other ships. The dynamic nature of the problem is inherent in the solution variables which represent a chronological sequence of events for each ship. In mathematical programming models which do not take into account the dynamic nature of the problem each succeeding event in time must have associated with it a distinct set of solution variables. This makes the number of solution variables roughly proportional to the length of the problem period. For problems covering any practical length of time the number of variables quickly grows beyond all manageable proportions.

It would seem, then, that practical analytic approaches must involve a dynamic programming formulation of the problem. Here two problems immediately arise. First, it is difficult to choose a workable subdivision of time for the dynamic programming model because the ships all travel at different speeds and the lengths of different trips vary greatly. Second, the state variables for any such model must adequately describe all ships and all unshipped cargoes. This requires a very large number of both state and policy variables. Such a dynamic programming problem run on a computer would require an amount of memory space far greater than could be stored in internal memory. The use of external memory capacity would require impractical amounts of computer time.

It appears that, with the present level of understanding of the dynamics of the posed bulk cargo shipping problem, practical results from analytic models of the overall operation are a number of years away. Analytic approaches to more limited problems, however, may still provide immediate practical results. For example, at ports with draft restrictions, under what conditions is it more advantageous to use lighters to discharge cargo instead of arranging a two port discharge? This is a question which must be solved before the possibilities of either technique may be incorporated into the scheduling problem. On this type of problem mathematical analysis holds great promise.

Applicability of Simulation

Several investigators, Weldon (1959) and Datz, et al. (1964), have turned to computer simulation as a decision making aid until analytic models can be developed to solve large shipping problems. Computer simulation will not solve the shipping problem. It can, theoretically, provide no information that cannot be provided by traditional, pencil and paper analysis. It does provide a vast amount of computational power which will allow ship schedulers to look into the future and observe the possible or probable consequences of policies and decisions which must be made now.

The benefits to be gained from simulation arise in three different phases of the simulation effort. The initial problem analysis, necessary before a process or system can be simulated on a digital computer, and the development of the computer programs provide motivation and guidance to the investigator in studying every aspect of the problem. The return in terms of human understanding of the process or system is often sufficient to justify this phase of the simulation effort as an end in itself. The data collection and tabulation effort often provides a readily accessible body of facts and information of use in the entire administrative work of the company involved. The use of the working simulation routine serves as a decision making aid in handling current problems and also can assist in both the development and testing of analytic models of the system.

As stated earlier, analytic methods have been, and still are highly useful in attacking pieces of the problem. Simulation gains its greatest advantages in allowing managers to evaluate the effect of incorporating the solutions to these pieces into the whole system if, at worst, only on a "try it and see" basis. Weldon (1959) says:

> "All of us are engaged, in one way or another, in research on maritime affairs, but I think the plain facts of the matter are that many of the really important problems are too tough for us. As a result, we tend to single out pieces and then we hack away at them. This unfortunately leaves the operating management of steamship companies right where they always were-solving the important problems by the old method of sailing ships."

The simulations developed by the Matson Navigation Company (Weldon, 1959) and by the Maritime Administration (Datz et al., 1964) were both designed to deal with liner operations. They study ship operations over fixed routes with stochastic time parameters and stochastic cargo requirements. In the industrial shipping problem considered here cargo requirements may be determined before hand from long term ore sales contracts and time parameters may be estimated more exactly, hence, the problem is essentially deterministic in nature. The routes of ship travel in this case are variable and must be established by the simulation program instead of being predetermined. In simulating a deterministic system the simulation program is reduced to the status of being simply a high speed calculator. At the same time the programming effort and data collection and analysis are both greatly reduced; therefore the practical advantages of simulation may still be just as great. The Users Manual for The MARAD Fleet Operation Simulation (1964) states that the Maritime Administration simulation is at its greatest disadvantage on small scale problems because of the great effort required for collection and preparation of input data. A simulation of an industrial fleet operation would not be at such a disadvantage on small problems primarily because the input information relating to cargo requirements is greatly simplified.

Summary

The present chapter has described the variables and parameters of importance in industrial shipping. The parameters can be predicted with sufficient accuracy and reliability that the problem can be stated in deterministic terms. Since the techniques of mathematical analysis have thus far, been unable to successfully deal with the large, more important problems of ship scheduling, managers have turned to simulation as a tool in studying these problems. Weldon (1959) draws an analogy between simulation and time-lapse photography of, for example, a growing plant. He says, "I would like to see some technique where by we can sail ships for hundreds of years on a greatly speeded-up time scale and then sit there and look at the whole operation until we understand it."

Chapter Three

THE INDUSTRIAL FLEET SIMULATION

Introduction and Purpose

In the commercial shipping industry a decision by a company to undertake a simulation of its shipping operation is not one to be taken lightly. Any serious simulation effort involves a tremendous initial effort and expense. If this effort is to be well spent it must be coordinated with the rest of the company's management effort to insure that the simulation will be useful in as wide a range of problems as possible. In the Matson Navigation Company effort (Weldon, 1959) it was estimated that the programming and coding alone would require six man years of work. Even after a first working program is prepared a great deal of time is required in logic debugging and alteration and in evaluating the realism of the result. Along with this effort, company planners must learn how to use the simulation to its greatest advantage.

For the purposes of the present study time became an important factor. It was, therefore, decided that the first attempt at simulation of an industrial fleet operation should be kept as simple as possible to insure that a working program could be completed in the allotted time. Since this work is to date unsponsored student research, a building block, successive revision approach is envisioned in the attempt to produce a realistic simulation of the entire industrial shipping operation of The Corporation.

The purpose of this chapter, then, is to present a general description of the entire Industrial Fleet Simulation as it may appear when completed and to give a detailed description of the first program to be written. This first program is, in fact, only one small part of what will finally be required.

General Description of the Industrial Fleet Simulation

The general description of the overall simulation to be presented here represents a "first revision" of the concepts based on the experience of developing the first simulation program. The first simulation program will itself be presented in the next section.

Final Objective of the Simulation

The objective of the Industrial Fleet Simulation is to provide a management and planning tool which will:

1) Assist in testing and evaluating the consequences of specific ship scheduling policies and practices;
2) Aid the actual scheduling of owned and time chartered ships;
3) Aid the prediction of future bulk tonnage and F. I. O. charter requirements;

4) Aid in the economic evaluation of decisions which must be made daily;

5) Be capable of being linked with a simulation of the iron ore mining operation to provide a working model of the entire mining and shipping operation of The Corporation.

Basic Structure of the Simulation

The final versions of the Industrial Fleet Simulation will contain three stages which will be run as independent programs or be connected by some chaining technique. These three stages will be referred to as the Input Routine, the Scheduling Routine, and the Accounting and Editing Routine.

Input Routine. The Input Routine will read from cards all the parameters of the ships and trips in the operation to be simulated and will prepare parameter lists on tape to be read later by the Scheduling Routine. The primary function of the Input Routine will be to read from cards all the information needed concerning ore sales contracts and back haul cargo contracts, and then prepare a list of cargo requirements and associated parameters as described on page 24. This input information will contain only the absolute requirements of the customers for delivery of iron ore or other back haul cargo as stated in the contracts. Programmed into the Input Routine will be the policies followed by the Ore Sales Company for distributing their ore sales evenly in time and for matching ore production capabilities. Following these policies and customer requirements the Input Routine will generate a list of cargo requirements described by parameters for tonnage, trip number, earliest delivery date, latest delivery date and any other parameters which may be required. All of these cargo requirements will be stored on tape to be read by the Scheduling Routine.

The Input Routine may also serve as the link to a simulation of the mining operation, since information concerning future mine production would have to be used in generating the cargo requirements. The exact nature of how this connection can be made has not been determined and is beyond the scope of this paper.

The Scheduling Routine. The Scheduling Routine will read from tape the information generated by the Input Routine. It would then generate schedules for all ships to be used and produce a chronological record of all trips made to include ship number, trip number, cargo parcels delivered, and date. Again, the policies and decision criteria for the ship scheduling will be programmed into the routine with minor changes made through input control parameters. The policy parameters are discussed more fully in Chapter Four.

The scheduling will be performed by making two or more successive passes through the schedule generating portion of the routine. On the first pass only owned and time chartered ships will be scheduled. Since the cargo requirements are always greater than the carrying capacity of the owned and time chartered ships a number of cargoes will be delivered late and others will not be shipped at all. The program will then look at the late and undelivered cargo and at the manner in which the owned and time chartered ships were used. It will calculate the total additional tonnage needed to satisfy the total cargo commitments and establish a priority list of trip numbers for the allocation of the additional tonnage. A list of ships available for charter will then be examined and a sufficient number of these ships will be selected to satisfy the tonnage required. These ships will then be scheduled; their cargoes will be subtracted from the initial cargo requirements; then, the owned and time chartered ships will be completely rescheduled to satisfy the reduced initial cargo requirements (See Appendix B). This process could be repeated several times but the number of refinements performed on the schedule will depend entirely on the degree of sophistication and experience acquired by the people developing the program.

The Accounting and Editing Routine. Using the simulation will require a great deal of careful and skillful analysis of the output. Since simulation itself cannot "optimize" ship scheduling, much depends on the analytic skill and insight of the people who are using the simulation. To facilitate the analysis of results the Accounting and Editing Routine will read from tape the information from the Scheduling Routine on ship and cargo movement, will calculate all numerical quantities, such as the value of the cost function ϕ described on page 29, and generate all tables, lists, and graphs, required by the analysts. Much of this output will be redundant because the purpose at this point will not be to conserve paper but to present, in the most useful form and format, information describing the relationships which the analysts wish to study.

The three routines described above will be made into separate programs mainly because of core memory requirements. Within each routine the execution time is greatly reduced if all of the numerical quantities required can be stored in core memory. Since the program instructions must also be stored in core memory the size of the core memory becomes a significant programming consideration. Since a very small proportion of the total numerical information is required by more than one of the routines, it is possible to greatly reduce core memory requirements by separating the three routines into independent programs. Passing information between routines is done by writing and reading magnetic tapes while core memory contains only one routine at a time with its associated data.

It should be emphasized that the simulation as described above will require a considerable expenditure of time, effort, and money. It will be the result of numerous revisions and rewritings. It will have to grow with the men who will develop it. The final form of the simulation cannot be clearly envisioned in any great detail until further progress is made. As a first step in this direction the program described in the following sections of this chapter has been written. It represents only that portion of the Scheduling Routine which schedules the owned and time chartered ships to meet the set of initial or reduced cargo requirements. For purposes of simplicity it will, however, be referred to as the Scheduling Routine. In order to get some idea of the realism of the result, cost parameters are included in the program and used to calculate several quantities for use in evaluating the schedule. These calculations would later be performed by the Accounting and Editing Routine. In addition a small Editing Routine was developed to prepare two tables for use in correcting the program itself. These constitute an embryonic Accounting and Editing Routine.

The Scheduling Routine

General

The first version of the Scheduling Routine was written in the FORTRAN II language for use on an IBM 7072 computer. This was more a matter of necessity than choice, since this was the only computer and compiler language available. For the present purposes both the language and the computer (10k core memory) were adequate, but when the entire simulation is completed large problems may well exceed the 10k core memory. Further development of the simulation would also be facilitated by use of one of the new simulation languages such as SIMSCRIPT (Markowitz, Hausner, and Karr, 1963).

At the outset it was not certain what the memory requirements would be. To insure that the first version could be completed without overflowing the 10k memory of the IBM 7072 the real shipping operation was considerably reduced and simplified. The resulting hypothetical operation to be simulated is described in the next section below. Also, to aid in reducing memory requirements, it was decided to use a very coarse resolution in describing the hypothetical problem on the computer. Travel times were described in whole days, cargo in thousands of tons and costs in thousands of dollars. Scaling the parameters in this manner allowed several pieces of data to be packed in one word of core memory.

The simulation must take a specified set of cargo requirements and a set of owned and time chartered ships and generate a schedule describing what trips each ship makes and what cargo is hauled for the entire specified problem period.

The Hypothetical Problem to be Simulated

Iron ore is shipped from Peru to customers in twenty-one ports located in Japan (8 ports), Eastern United States (4 ports), Northern Europe (6 ports), and Southern Europe (3 ports). Back haul cargoes of oil are shipped from the Persian Gulf and Sumatra to California. Coal is shipped from the Eastern United States to Japan. The Shipping Company has at its disposal sixteen owned and time chartered ships which vary in maximum capacity from 30 thousand tons to 66 thousand tons.

Ports, Port Areas, and Trips. For purposes of the simulation the ports involved in the operation will be grouped by geographical area and by port characteristics (e.g. draft limitations) so that scheduling policies and decision criteria may be stated for a whole group of ports instead of for each individual port. Trips will then be defined only between groups of ports. In this case it will be assumed that the eight ports in Japan, the four in the Eastern United States, the six in Northern Europe and the three ports in Southern Europe are sufficiently like their geographic neighbors in port characteristics that the geographic groupings do not need to be subdivided (in reality the Japanese and Northern European groups would have to be subdivided). In this problem, then, there will be eight port areas, each assigned a number as shown in Table 1. Among these eight ports it is possible to define

56 different one way trips. Company policy, however, dictates that a number of these trips will never be made. For example, ships will never make the trip from Japan to California or from Peru to Sumatra. Table 2 gives the list of trips which will be permitted if cargo is available for those trips. As shown in Table 2 only one type of cargo is associated with each trip. Trips 9, 10, 11 and 15 are not actually used but were assigned numbers to facilitate expanding the simulation if it was desired. Trip 20 is used to indicate a lay-up condition in the home port at Peru. No ship will ever be in a lay-up condition away from Peru. It should be noticed that the trip numbers are assigned in groups by destination port area. This is to facilitate identifying the next port of call since this determines the set of policies to be used in assigning the ship to another trip.

Ships. Each ship is also assigned a number and the ships are grouped for purposes of stating assignment policies. All ships within the same group will be controlled by exactly the same policy. Table 3 gives the ship numbers and the tonnage of each ship by group. In this case the grouping is based on tonnage only, but this need not always be true.

Table 1

PORT AREA NUMBERS

Port Area	Numbers
Peru	1
Japan	2
Eastern United States	3
California	4
Northern Europe	5
Southern Europe	6
Persian Gulf	7
Sumatra	8

Table 2

AUTHORIZED TRIPS

Trip Number	Trip	Cargo
1	Japan to Peru	In ballast
2	California to Peru	In ballast
3	Eastern U. S. to Peru	In ballast
4	Northern Europe to Peru	In ballast
5	Southern Europe to Peru	In ballast
6	Peru to Japan	Iron Ore
7	Eastern U. S. to Japan	Coal
8	Peru to Eastern U. S.	Oil
9	Sumatra to Eastern U. S.	Oil
10	Northern Europe to Eastern U. S.	In ballast
11	Southern Europe to Eastern U. S.	in ballast
12	Sumatra to California	Oil
13	Persian Gulf to California	Oil
14	Peru to Northern Europe	Iron Ore
15	Southern Europe to Northern Europe	Iron Ore
16	Peru to Southern Europe	Iron Ore
17	Eastern U. S. to Southern Europe	Grain
18	Southern Europe to Persian Gulf	In ballast
19	Japan to Sumatra	In ballast
20	Ship Laid-up	

Table 3

SHIP NUMBERS AND TONNAGE

Group	Ship Number	Tonnage
1		30k
	1	30k
	2	34k
	3	34k
	4	
2		48k
	11	48k
	12	43k
	13	43k
	14	
3		54k
	21	56k
	22	53k
	23	
4		
	31	65k
	32	66k
	33	66k
	34	63k
	35	63k

Scheduling Policy

General. For purposes of simulation, broad statements of scheduling policy must be translated into a form more directly related to ships, ports, and trips. The scheduling policy to be used must specifically state, for each group of ports, the preferred next assignment or trip, in order of preference, for ships of each group. These preferred assignments and the order of preference will depend on conditions of cargo availability. For example, for all ships in Group 1 arriving in Japan, the policy must specify the preferred next assignment for all possible conditions of cargo availability.

Since the primary function of the fleet is to haul iron ore from Peru to customers in four port areas or groups, the scheduling policy must, necessarily, be more complex for ships arriving at the home port of Peru. The possibility of making back haul cargo trips, however, means that next assignment policies must be specified for all ports.

The policies as programmed represent simply a formal expression of assignment preferences in specific situations. Consider, for example, a ship in Group 4 (the class of largest ships) arriving at Peru, Port No. 1. The Shipping Company prefers to keep Group 4 ships operating in the Pacific Ocean as much as possible to avoid restricting their cargo load for passage through the Panama Canal. Since the only outbound trip from Peru which does not pass through the Panama Canal is Trip 6 to Japan, this is the first choice as a next assignment for ships of Group 4. If there is no cargo available to justify making this trip, then it is preferred to send the ship on the shortest possible trip through the Panama Canal. This establishes Trips 8, 14 and 16 as the next choices, in that order. The preference list of trip numbers 6, 8, 14 and 16, then, partially defines the scheduling policy at Port No. 1 (Peru) for Group 4 ships. The preference lists may be established on the basis of the most economical utilization of ships, on the basis of adequately satisfying cargo requirements, or more reasonably on some compromise between the two.

Once a preference list is established for all combinations of port groups and ship groups, the selection of a particular assignment from a preference list must still depend on what cargo is available for each trip in the list. The manner in which these selections were made in the first version of the Scheduling Routine is described below by port area. The policies stated below are somewhat arbitrary. They were used simply for the purpose of demonstration and were not selected with any great care since detailed scheduling information from Marcona was not available when the work was done.

For the present purposes, the ships are grouped only by cargo capacity and the scheduling policy varys according to ship group only at the home port of Peru (Port Area 1). Further work with the simulation should obviously involve refinements in these two areas.

The policies which determine the routing of ships on successive trips have been kept fairly simple for the first simulation. Several terms must be defined before stating these policies. A suitable cargo is one which can fill a ship to within ten thousand tons of its capacity for that trip and, if the ship departs immediately, will be delivered after the early date (E(r)) and before the late date (L(r)) specified for that cargo. Late Cargo is cargo which will be delivered after the late date (L(r)) even if the ship departs immediately. The scheduling policies are stated below for each port area.

Port Area 1 (Peru). For each ship in Group 4 (Ships 31 through 35), Trips 6 (to Japan), 8 (to East. U. S.), 14 (to N. Eur.), and 16 (to S. Eur.) are checked in that order. The first trip found to satisfy either of the following two conditions will be selected for the next trip: Condition 1) a suitable cargo is waiting; Condition 2) more than 10 thousand tons of late cargo are waiting. If none of these ports satisfy the conditions, the ship is laid-up for ten days at which time the checks are performed again. If Trip 16 to Southern Europe is selected, a further check is made to see if there is suitable or late cargo in the Persian Gulf for Trip 13. If so, the ship will continue on from Southern Europe to the Persian Gulf in ballast and pick up a load of oil for California. This policy will keep the largest class of ships operating in the Pacific Ocean as much as possible.

For each ship in Group 3 (Ships 21 through 23), Trips 6, 16, 8 and 14 will be checked in that order. Except for the order in which the trips are checked the assignment procedure is exactly the same as for Group 4 ships.

Group 2 (Ships 11 through 14) and Group 1 (Ships 1 through 4) are assigned according to the same policy. Trips 14, 16 and 8 are checked in that order. The first trip for which either of the following two conditions is satisfied will be selected as the next trip: Condition 1) there is more than ten thousand tons of late cargo waiting; Condition 2) there is a suitable cargo available which will be late if delivered by the next Group 1 or 2 ship to arrive in Peru. If none of these trips has cargo satisfying either of these two conditions, then Trip 6 (to Japan) is checked. If there is more than ten thousand tons of late cargo waiting for Trip 6, the ship will make Trip 6 next. If there is a suitable cargo available for Trip 6 which will be late if delivered by the next Group 3 or 4 ship to arrive in Peru, then Trip 6 will be selected. If Trip 6 is not selected, then the first of Trips 14, 16 or 8 which were found to have a suitable cargo available will be selected. If there are no suitable cargoes available the ship is laid-up for ten days and then the checks are performed again. This policy will insure that the smaller ships will operate primarily on trips passing through the Panama Canal.

Port Area 2 (Japan). All ships arriving in Japan are subject to the same policy. If there is a suitable cargo of oil available in Sumatra, Trip 19 (to Sumatra) will be made in ballast. If not, Trip 1 (to Peru) will be made in ballast.

Port Area 3 (Eastern United States). All ships arriving in Eastern United States are subject to the same policy. If there is either a suitable cargo or more than twenty thousand tons of late cargo for both Trips 17 and 13, then the ship will take Trip 17 to Southern Europe, Trip 18 to the Persian Gulf, and Trip 13 to California. If this is not the case, then Trip 7 (to Japan) will be checked. If there is a suitable cargo or more than thirty thousand tons of late cargo for Japan, Trip 7 is selected. If this also is not the case, then the ship will return in ballast to Peru (Trip 3).

Port Area 4 (California). All ships will return in ballast to Peru (Trip 2).

Port Area 5 (Northern Europe). All ships will return in ballast to Peru (Trip 4).

Port Area 6 (Southern Europe). All ships arriving in Southern Europe are subject to the same policy. If there is a suitable cargo available for Trip 13 or more than thirty thousand tons of late cargo for Trip 13, then the ship will make Trip 18 in ballast to the Persian Gulf, and will then make Trip 13 with oil for California. If no such cargo is available the ship will return in ballast to Peru (Trip 5).

Port Area 7 (Persian Gulf). All ships arriving here will make Trip 13 with oil for California.

Port Area 8 (Sumatra). All ships arriving here will make Trip 12 with oil for California.

The groups of ships defined in Table 3 may be considered to be independent fleets, each subject to its own assignment policy. This permits additional flexibility in the manipulation of the operation since ships may be transferred from one group or fleet to another. If, for example, a given policy results in an excess of shipping in one area and a deficiency in another, the situation may be corrected by changing the policy statements or by shifting one or more ships from one group to another. This may result in less efficient use of a ship which is transferred but may also provide much better service in meeting cargo commitments.

The Simulation Program

General. Simulation models are generally one of two types. A "time step" model proceeds through the simulation period in a sequence of equal steps whether or not any activity occurs at each step. The simulation of ocean shipping is more economically done with a "critical event" model. In these models the simulation proceeds in unequal time steps from one "critical event" to the next. A critical event is essentially an action which causes a change in the state of the operation. In this simulation, a critical event occurs when a single ship completes one trip and becomes committed to another. A trip is defined to include the port servicing for the trip, the loading of cargo, travel to the destination port, and the discharging of the cargo. Trip time covers all of these activities. The critical event, then, represents the point in time when the ship has completed discharge of cargo and is about to begin servicing for the next trip. Since there may be relatively long periods of time between critical events during which all ships are simply at sea, the critical event model will provide more efficient use of computer time than will a time step model.

Program State Variables and Parameters. The structure of the program can best be described in terms of the variables used and the manner in which they are manipulated.

The term "state" will be used as an undefined term. Intuitively it will represent everything that must be known about the operation in order to determine the future course of action. Once the scheduling policies have been defined, the transition to the next state is entirely dependent upon the present state.

In this problem the state must describe, as a minimum, all of the cargo remaining to be shipped, and the current destination (or trip) and date of arrival of each ship in use. The state is defined in computer core memory as three subscripted variables, ICARG(M), ISTAT(I,J), and IQUE(K).

The variable ICARG(M) describes the cargo remaining to be shipped. It may be thought of as a list of cargo requirements divided into sublists for each trip. The first word of each sublist contains the trip number and the number of requirements or "parcels" in the sublist. Each word of a sublist, other than the first word, contains three parameters describing a cargo parcel waiting to be shipped on the trip numbered by the first word of the sublist. These three parameters are the early date (E(m)), the late date (L(m)) and the tonnage remaining (W(m)). The parameters are extracted from the words of the list by function subprograms.

The current state of the ships is described by two variables, IQUE(K) and ISTAT(I,J), as a matter of convenience. In ISTAT(I,J), each value of I corresponds to one ship in use.

In this case there are sixteen ships, hence I=1,2,3,...,16. In this program J varies from 1 to 5 providing memory space for up to five variables describing the ship. In the present case only two of these parameters are needed. ISTAT(I,1) indicates the trip that the ship is currently making and ISTAT(I,5) gives the identification number (from Table 3) of the ship. ISTAT(I,4) is used for the arrival date, but this is redundant and may be deleted since the arrival date is also stored in IQUE(K).

Each word of IQUE(K) contains the date of a critical event and an index number that indicates the value of I in ISTAT(I,J), which will identify the ship to be associated with the critical event. IQUE(K) is used as a "pop-up" list. The words are stored in order of date so that IQUE(1) always represents the next critical event to be considered.

The parameters pertaining to the ships are all stored in memory under the variable name MTRIP(I,L). The subscript I corresponds to I in ISTAT(I,J) and represents the index number of a ship. The subscript L corresponds to a trip number. Each word of the array contains three parameters pertaining to Ship I making Trip L: maximum capacity, time (in days) required to make the trip, and total cost. As in the case of the cargo parameters, each quantity is extracted from the memory word by a function subprogram.

Processing Critical Events. The manner in which critical events are processed in the computer is a fairly routine programming problem. It is not the intent here to discuss the details of the computer program; hence, the processing of critical events will be described as briefly as possible. The computer first goes to IQUE(1) to determine the date of the next critical event and the value of the ship index, I. It then looks at ISTAT(I,1) to determine the number of the trip that the ship is completing. From this trip number, the port at which the critical event will occur is determined. The computer then branches to that part of the program which reschedules ships arriving at this port. A new assignment is selected according to the policies stated on pages 51-54. The computer writes on an output tape the date of the critical event, the ship number, the number of the newly assigned trip, and a description of the cargo carried. It also places the new trip number and new arrival date in ISTAT(I,1) and ISTAT(I,4), respectively. Then, a word is created which contains the ship index, I, and the new arrival date. This word is inserted into the IQUE list according to date and all of the words of the list are moved up one place. The old IQUE(1) is thus replaced by the next word in the list. The new IQUE(1) will then contain the date of the next critical event and the index of the ship involved. The process is then repeated.

Summary

The development of a useful and practical Industrial Fleet Simulation will require the development of three independent programs. The three programs have been named the Input Routine, the Scheduling Routine, and the Accounting and Editing Routine. Input to the simulation will contain the required operating parameters of all ships to be considered, the initial disposition of all ships, and all needed information concerning ore sales contracts and back haul cargo contracts. This input will be made via the Input Routine which will put all parameters into the proper form for storage in core memory during the execution of the Scheduling Routine. The Input Routine will also reduce the ore sales contract and back haul cargo contract commitments to a list of cargo requirements distributed over the simulation period. All of this information will be stored on magnetic tape to be read by the Scheduling Routine.

The Scheduling Routine is the heart of the simulation. It reads the tape prepared by the Input Routine and generates a chronological record of ship movements and cargo handling based on predetermined scheduling policies. This Scheduling Routine will contain two main parts. Part One will schedule all owned and time chartered vessels in an attempt to satisfy all the cargo requirements. Part Two will look at the results of the scheduling of the owned and time chartered ships and will select a sufficient number of the ships available for F. I. O. charter to handle the unsatisfied cargo requirements. It will schedule these F. I. O. charter ships, subtract their cargoes from the initial cargo requirements and return control to the first part of the program which will then reschedule the owned and time chartered ships. The final resulting schedule of ships and cargo movements will be transferred to the Accounting and Editing Routine via magnetic tape.

The Accounting and Editing Routine will generate, from the basic schedule, cost figures, tables, and schedules required by the analysts who will study the results.

The first program written, which has been described in the preceding section, represents a first version of Part One of the Scheduling Routine. It was necessarily crude in form and function. Recommendations for refinements and a discussion of the lessons learned from this program are presented in the next chapter.

Chapter Four

INPROVEMENTS AND FURTHER DEVELOPMENT

Introduction and Purpose

Chapter Three described the complete Industrial Fleet Simulation as it is envisioned in its final form and also described the first computer program written to function as part of this simulation. Since the first version of the Scheduling Routine represents only a small part of the complete simulation, this first attempt cannot by itself satisfy any of the objectives stated in Chapter Three (page 37). The work required and the results obtained from this first effort have, however, done much to point the way to the successful, complete simulation of an industrial shipping fleet. Several improvements in programming procedures have come to light for use in the second version of the Scheduling Routine. A general "feel" for the simulated operation has been generated. This greater understanding has clarified the concept of the structure of the final simulation program. It is the purpose of this chapter to describe the immediate programming improvements which can be made in the second version of the Scheduling Routine and to lay out the work remaining to be done.

Improvements to be Made in the Scheduling Routine

Identification of Ships

In the program as written identification numbers were assigned to each ship (Table 3) to indicate the group to which the ship was assigned. This system allowed for a maximum of ten ships in each group or a total of fourty. Since only sixteen ships were used, an index number, I, was assigned to each ship which indicated the value the subscript to be used in the state variable ISTAT(I,J) for that ship and also in the parameter array MTRIP(I,L). One identifying number for a ship is adequate for both purposes, hence the present arrangement is redundant and wastes memory space. In the next version of the simulation only the index number will be used. The ship groups can be established by defining a set of index numbers for each group. A computer transfer of control such as a FORTRAN computed GO TO statement may then be used for branching to the proper scheduling policy routine, depending on the value of the ship index. It thus becomes unnecessary to store an identification number in ISTAT(I,5).

Sequencing Critical Events

The use of the pop-up list, IQUE(K), to sequence critical events is also redundant in terms of memory space. The IQUE(K) list may be deleted completely. The next critical event can be determined by simply searching

ISTAT(I,4), 1=1,2,...,16, for the smallest arrival date. This will require fewer program instructions and will also eliminate the need for one subscripted variable, IQUE(K).

Printing Out Debugging Information

A great deal of the time required to develop a simulation is devoted to debugging after changes or additions have been made to the program. It is therefore very helpful to provide in the printed output sufficient information to tell the programmer exactly what the computer is doing and what quantities are being used as the simulation progresses. Diagnostic print instructions should be inserted so that the programmer can quickly trace the execution through the program. In addition, provision should be made to print selected portions of the ICARG(M) and ISTAT(I,J) state variables at critical points to assist in checking the scheduling policy logic. The inclusion of diagnostic aids in a simulation routine is, perhaps, more important than in other types of programming because it may be expected that the program itself will be continually changed as more is learned about the process or operation being simulated.

Parametric Representation of Scheduling Policies

One of the chief objectives of the Industrial Fleet Simulation is to study and evaluate various scheduling policies. To do this many successive runs of the simulation will have to be made, each using a somewhat different set of scheduling policies. In the first version of the Scheduling Routine the specific scheduling policies used are expressed in program statements. Changing these policies requires changing the program itself. In the future this will be extremely inconvenient and inefficient. Every time a program is changed there is a possibility of creating new logic or punching errors, hence necessitating further debugging.

An examination of the policies used and the manner in which they were programmed in the first version of the Scheduling Routine reveals that it should be possible to write one routine which would represent a broad class of possible scheduling policies. Each policy in this class would be characterized by a set of parameters which would be read as input data at the beginning of the execution of the simulation. The programmed policy routine and a given set of parameters would constitute, what might be called, a parametric expression of a scheduling policy. This would permit changes in scheduling policy to be accomplished largely through the use of input data, parameter cards.

Certainly the trip numbers given in a preference list as described in Chapter Three (pages 49-51) may be considered to be parameters describing a specific policy. A simple list of trip numbers is not sufficient, however, since the preferences expressed in the list are not, in general, unconditional. For example, for ships in Group 3 arriving at Peru a preference list of Trips 6, 16, 8 and 14 was used. However, Trip 6 was preferred only on the condition that there was a late cargo waiting for Trip 6 or there was a suitable cargo for Trip 6 and no late cargo for the other three trips. (The terms suitable cargo and late cargo are used as defined on page 51.) Similarly, a late cargo for Trip 8 or 14 may be preferred over a suitable cargo for Trip 16. These conditional preferences require, in addition to a preference list, several parameters which alter the preference order based on particular cargo conditions.

Initially the conditional preferences should be kept as simple as possible. The policies used in the first version of the Scheduling Routine can be described using three conditions. These conditions can best be described by example. Consider the preference list given in Table 4 with conditions 1, 2 and 3 applied to the trip numbers in the list. In Table 4, condition 1 means that either a suitable or a late cargo for Trip 14 is preferred over any cargo for trips lower in the list. Condition 2 on Trip 16 means that a late cargo for Trip 16 is preferred over any cargo for lower trips but a suitable cargo for Trip 16 is preferred only over suitable cargoes for lower trips. Condition 3 subscripted by (i) indicates that a late cargo for Trip 6 is preferred over any cargo for lower trips, but a <u>suitable</u> cargo for Trip 6 is preferred <u>only</u> if it <u>cannot</u> be delivered on time by the next available ship in Group i. Again, in Table 4, Trip 20 indicates a lay-up condition at Port 1.

Table 4

PARAMETRIC REPRESENTATION OF SCHEDULING POLICY

Preference List	Conditional Mode
14	1
16	2
8	2
6	3(i)
20	

Such a system for parametrically representing the scheduling policies will permit most of the scheduling decisions to be made by calling a single subroutine which will operate on a specified conditional preference list to generate an assignment. As the simulation is developed and improved more sophisticated preference conditions may be defined using a more elaborate parametric representation of decision policies. Some policies, which cannot be conveniently defined with the parameterization scheme in use, will still have to be expressed as programmed instructions.

The parametric representation of scheduling policies will permit the manipulation of these policies by simply changing input parameter cards. This will greatly reduce the time necessary to prepare for a simulation run. It will also provide two less important, but significant, benefits. The reduction in the required program instructions will reduce the core memory requirements. In addition, when a series of runs are to be made for which the policy changes can be made solely by changing input parameters, an object deck of the program can be punched on the first run so that the compile stage may be eliminated on the succeeding runs. This may result in significant reductions in computer run time. The first version of the Scheduling Routine required approximately three minutes to compile and between three and three and one half minutes to execute on an I.B.M. 7072 computer for a simulation period of one year. Hence, reductions of almost 50% in computer time may be achieved when the compile stage is eliminated by using an object deck of the program.

Major Considerations in Further Development of the Simulation

There are several problems which have not yet been considered because, to date, the information and data needed for study of these problems has not been obtained from Marcona Corporation. Five of these problems are discussed in this section because their resolution is vital to the future development and use of the Industrial Fleet Simulation.

Maintenance of Ships

Every ship from time to time must be taken out of service for scheduled or unscheduled maintenance. The time required for minor repairs and refitting between trips may be included in the delay time discussed on page 20. Major repairs, however, can seriously disrupt shipping schedules and should be considered separately in developing the Industrial Fleet Simulation. The maintenance history of each ship should provide sufficient information to plan a good program of scheduled maintenance for each ship. The scheduled maintenance program could be easily incorporated into the simulation. Repair and maintenance contracts must be made in advance with shipyards and drydock facilities. This places a further constraint on the ship scheduling since ships must be utilized in such a way as to insure that the ship will be in the vicinity of the repair facility at the appropriate time. This will be a problem only in the scheduling of owned and time chartered ships since the owners of ships under F. I. O. or bulk tonnage contracts are responsible for satisfying contract agreements regardless of maintenance or repair requirements of their ships.

Unscheduled maintenance and repair necessitated by breakdown is a much more difficult problem which will affect all ships employed by The Shipping Company. If a review and evaluation of the breakdown experience of the ships used, indicates that the problem is of significant proportion and must be included in the simulation, only two approaches at present seem feasible. If it is desired to study the consequences of specific characteristic breakdown situations, the breakdowns may be generated externally and entered into the simulation by the use of parameter cards. In this case the simulation would handle them in an entirely deterministic manner similar to the way scheduled maintenance is handled. If the purpose is only to improve the realism of the simulation results the breakdowns may be generated stochastically by an internal routine. This would require a greater effort in statistically analyzing the breakdown experience of each ship considered.

Stochastic Generation of Delays and Other Uncertainties

The problem of uncertainty in shipping operations is one which will require a great deal of study in developing and evaluating any simulation. Ship schedules and the current situation in the shipping operation are subject to frequent, sometimes drastic and always harrassing changes. It will be necessary to carefully categorize these changes, to catalogue their causes and to count the frequency of the events associated with the causes. This must be part of the study of delays suggested in Chapter Two (page 20) since unexpected delays in ship arrivals or departures are a major cause of frequent changes in ship scheduling.

If this study indicates that the delays cannot be realistically accounted for in the simulation by simply adding average delay times to trip times as was suggested in Chapter Two (page 20), then it will be necessary to also generate delays (other than those caused by ship breakdown) stochastically within the simulation. The effort required for input data preparation increases rapidly with the number of factors which must be generated in this manner. Hence, it is not clear at this stage whether this effort will be worth-while in terms of the realism of the resulting ship schedule.

Future Growth of the Shipping Operation

The development of the complete Industrial Fleet Simulation may be expected to require a considerable length of time. Hopefully, it will also be usable for a long time. During the development and use of the simulation Marcona Corporation will undoubtedly expand its shipping operation by gaining new customers, adding ships to its fleet, gaining a greater variety of back haul cargoes, and possibly opening new sources of iron ore. In fact, the simulation itself may be used to study the advisability of particular actions in any of these fields. Great care must therefore be exercised to insure that expansions in any of these areas may be easily incorporated into the simulation without major reprogramming. The program must be structured so that more complex and elaborate grouping of ships and ports may be achieved with a minimum increase in core memory requirements.

The parametric expression of scheduling policy as described earlier (page 63) will require further development and sophistication. The solutions to the programming problems arising from all of this will probably be mostly mechanical; however, the formulation of problems for study and the development of scheduling policy for use in the simulation will require increased ingenuity in the use of both empirical and analytic aids (see Chapter Five).

Variability Of Ore Grades

Iron ore is supplied to customers in at least seven different ore "grades". Most grades are further divided into several ore grade "specifications" to satisfy customer requirements. Some customer contracts call for one particular grade and specification; others call for a variety of grades and specifications in particular quantities. The customer may state different requirements for delivery dates for each grade and specification. It is possible, also, that a single ship may carry several ore parcels of different grade for a single customer. These considerations have been ignored in the development of the first version of the Scheduling Routine, since the nature of the ore contracts have not yet been studied in this respect. The variability of ore grades poses a formidable problem in the development of that portion of the Input Routine which reduces ore contract commitments to more manageable cargo requirements. The exact manner in which the problem is resolved will also depend on the manner in which mine production capabilities are introduced into the Input Routine.

Varying the Operating Speed of Ships

Occasionally when delivering a late cargo it becomes desirable to increase the operating speed of the ship to reduce the trip time. With the increase in speed there is a resultant increase in the fuel consumption and, hence, an increase in the cost of the trip. In a like manner it is sometimes desirable to decrease the operating speed and save fuel when delivering an early cargo or when another assignment is not immediately available for the ship. A detailed study of the operating characteristics of the ships and the economic consequences of late and early deliveries of cargo is needed to determine criteria for sensing situations in which a change from the standard voyage speed is desirable. If suitable criteria can be determined these alterations can be easily incorporated into the simulation; however, again the increased effort in data preparation may not be justified in terms of the increased realism of the results of the simulation.

Summary

This chapter has presented several direct improvements which may be made in the Scheduling Routine and has outlined a number of problem areas into which the simulation must be extended before it will be complete.

The first version of the Scheduling Routine made inefficient use of core memory space because of the use of redundant variables. This may be corrected by altering the ship identification scheme and the method of sequencing critical events. Further corrections and changes of the program will be facilitated by incorporating more debugging aids in the program. In order to permit easy changing of scheduling policy a parametric expression of these policies may be developed so that policy changes can be made by inserting parameter cards. This will greatly reduce the reprogramming required to use the simulation on a variety of problems.

Further aspects of the shipping operation which must be incorporated in the simulation include scheduling ship maintenance, generation of delays and other uncertain factors, providing for expansion of the operation, and variation of ore grades and ship travel times.

Chapter Five

APPLICATIONS AND CONCLUSIONS

Introduction and Purpose

When a tree ceases to grow it may be dead. The same may be true of a simulation program. After only a first attempt at a simulation program one quickly gets the impression that the time will never come when everything in the simulation will be perfect. When a simulation has been run several times and nothing arises to indicate that improvements or refinements in the program are desirable, then probably nothing new has been learned about the operation being simulated. If the developers and users of a simulation begin to look upon it as a finished product, then it has probably outlived its usefulness.

It has already been stated that one of the primary benefits of a simulation effort is derived from the fact that the requirements of the simulation both assist and force analysts to structure their thinking and studies and to incorporate the many smaller problems into the framework of the overall operation. In spite of these benefits it is still necessary to look at the completed working simulation and evaluate the usefulness and applicability of the output. Any model of a system or operation can be greatly misleading unless its users ask the question, "Is it applicable to the real world?" In the case of analytic models designed to provide "optimum" solutions it is not enough to inquire into the rigor of the mathematics. One must ask, "Is the mathematical, optimum solution also a practical, real, optimum solution?" Robert Skeele (1963) describes a linear programming model of a shipping operation very similar to that of Marcona Corporation. In his article he assiduously avoids discussion of the objective or cost function. The question just stated arises here. The answer may be found in Mr. Skeele's list of "Limitations and Disadvantages". The set of assumptions upon which the solution rests seldom holds up for as long as three months and the importance of timing the deliveries of cargo often make the choice of "optimum" schedules impossible.

In the case of a simulation model the results must be tested in terms of the "realism" of the output. For similar inputs of ships and cargoes, do the simulation and the real shipping operation produce similar schedules? The simulation results will provide a sound basis for making and evaluating decisions only if the answer to this question is yes. The realism of the Industrial Fleet Simulation will depend on both the structure of the program and the manner in which it is used. If either the problems formulated for study or the scheduling policies selected for use are unrealistic, then the resulting ship schedules will also be unrealistic. It is the purpose of this chapter to discuss briefly the concept of realism in the simulation of shipping, the manner in which the Industrial Fleet Simulation must be used, and the type of problems which can be profitably studied with the aid of simulation, and finally, to summarize the work which has been reported in this thesis.

Evaluating the Realism of the Simulation

The term "realism" must be carefully defined when used in reference to a simulation. When uncertainity exists in the future conditions and inputs to the real operation, a simulation cannot be expected to produce in advance an exact replica of the real ship itineraries and cargo deliveries. Its realism must be evaluated in terms of totals, averages and patterns of ship usage and cargo delivery.

It is difficult, if not impossible, to use future behavior of the real operation as a standard against which to judge the realism of a simulation since the future is uncertain and the best predictions of future conditions should already be incorporated into the simulation. If past history is used, the history of the real operation can be broken up into equal test periods. The recorded conditions of the operation at the beginning of each test period and the changing cargo commitments and availability of ships can be used to prepare inputs for the simulation. The results of the simulation can then be compared with the real operation for each test period. This comparison must be made on the basis of patterns of ship movements, patterns of cargo deliveries, totals for tonnage moved by owned and time chartered ships, tonnage moved by F. I. O. and bulk-tonnage chartered ships, tonnage delivered late, ton-days of trips in ballast, ton-days of shipping out of service for lack of cargo, and tonnage dropped by round off.

Patterns of ship movements include several considerations. When ships are grouped by size and operating characteristics, are the sets of ports visited by ships of each group generally the same in the simulated results and in the real operation? At each port is the frequency of visits of ships of each group comparable? The same questions should be studied for groups of ships formed on the basis of the type of charter arrangement or ownership. Other considerations will undoubtedly emerge as the simulation effort progresses.

The pattern of cargo deliveries also may be evaluated in several ways. Are the average parcel size and number of parcels delivered under each ore contract realistic? Is the number of parcels under each ore contract realistic? Are the parcels under each contract distributed realistially in time? Are the frequency and total tonnage of late deliveries reasonable and in line with past experience?

Detailed historical information on ship operating characteristics, cargo contracts, and past itineraries of ships is being prepared by Marcona Corporation in punch card form, but such information has not yet become available. This and the fact that the first version of the Scheduling Routine is only one part of the complete simulation have made it impossible to perform any detailed evaluation of the realism of the initial results. A sample of output from the first program is presented as Appendix B following this chapter.

Using the Industrial Fleet Simulation

Once the Industrial Fleet Simulation has been developed to a point where a usable degree of realism has been obtained, its use will be mainly in making trial and error studies of scheduling problems. Admittedly this sounds rather primitive, but many "primitive" techniques become practical when associated with the speed of a digital computer. The use of the simulation can be broken down into four phases.

Phase I. Policy Definition

Phase I may be called Policy Definition. During this phase the analysts must carefully define a complete, consistent set of scheduling policies covering all ports of interest, all ships to be considered, and all possible contingencies. The set of policies defined may contain current scheduling policies, new proposed scheduling policies or a mixture of both. In any case the analysts must clearly specify for future reference those specific policies which are to be evaluated, those which may be manipulated or altered, and those which are to be held constant. Also as part of Phase I a policy must be stated governing the manner in which cargo contract commitments are to be distributed in time. If more than one iron ore source is in the operation, a policy and procedure must be stated for satisfying contract tonnages from these multiple sources. The manner in which all of these policies are initially selected is not the subject of this thesis; but they may be selected on a somewhat arbitrary basis, or they may be based on the solution to smaller portions of the problem provided by analytic models. The primary purpose of the simulation is to aid in the evaluation of the consequences of these policies once they have been selected.

Phase II. Formulating and Programming Policies

Phase II is the programming of the policy decisions for incorporation into the simulation program. This phase will require some cleverness and experience in using the simulation. The policies defined in Phase I must here be formulated using grouping of ships, grouping of ports, the conditional preference lists described on pages 64-66 and additional program instructions as needed. It will be helpful if, in Phase I, the planners keep the parametric policy representation in mind while defining the policies to be used; the time required for Phase II will be greatly reduced if most of the policies can be easily described with the parametric representation. Special or unusual policies for particular ships or ports will require additional blocks of program instructions which must be included in the program as subroutines or by branching within the main program. This may require additional debugging. Also included in Phase II should be one or more runs of the simulation program using a set of test data to debug the additional instructions and to check the scheduling policy for completeness and consistency.

Phase III. Preparing Problem Situations

It may be desirable to study a given set of scheduling policies under several different situations. Phase III is the definition of these situations, the preparation of input data describing each situation, and preparation of the input parameters describing the ships and trips to be used. A situation will consist of a set of cargo contract commitments covering the period to be simulated and an initial position and employment for each ship. The situations may be based on the expected conditions of a specific future period, "worst case" conditions, "best case" conditions, or any conditions of special interest depending on the purpose of the study. Each situation will be represented by an independent set of data.

Phase IV. Execution and Analysis

Phase IV will be the running of the simulation for each set of data and the analysis of the results. The schedules and descriptive data produced for the several situations must be compared with one another and perhaps, with past experience and "expected" results. Surprising results should be checked to insure that they are not the result of errors or inconsistencies in the statement of scheduling policies or in input parameters. The nature of the analysis will depend on the purpose of the study but it must be aimed at evaluating those scheduling policies which were designated in Phase I as the policies to be evaluated. It will be likely that new considerations will arise during the analysis which may be investigated by altering those policies which may be manipulated and repeating the necessary portions of all four phases.

The four phases of the use of the Industrial Fleet Simulation as described here represent only one stage in a more comprehensive study of the problems of industrial fleet operation. Before this stage is reached a great deal of analysis and study of smaller, more restricted problems in the operation must be conducted. The conclusions and "solutions" obtained from these preceding studies form the basis for the policies and situations to be tested with the simulation. Since the policies, situations, and analysis depend on the purposes of the more comprehensive effort, and since the techniques used in the simulation program must be developed and refined through experience in using the simulation, the description of the four phases in the use of the simulation has been necessarily brief and somewhat sketchy.

Types of Studies for Which the Simulation May be Used.

In general, it appears that the advantages of computer simulation increase with the complexity of the shipping problem considered. For a simulation the programming effort and the computer time are roughly directly proportional to the number of ship groups and port groups which must be considered separately in the scheduling policy. For most analytic models used on a computer the programming time does not increase appreciably with the number of variables but the computer time increases exponentially or worse. On small problems, such as the scheduling of a single ship for its next voyage, simulation can, at best, be very inefficient and, at worst, totally misleading. It is best used in testing and evaluating broad scheduling policies and patterns of ship deployment, chartering practices, fleet composition, and the advisability of seeking new customers in new ports.

Marcona Corporation is soon to receive two new ships, one of 61,000 tons and one of 90,000 tons. Scheduling policies for the entire fleet must be adjusted to incorporate these new ships into the fleet. The company has had no past experience with such large and modern ships. The larger of the new ships will probably not be able to pass through the Panama Canal except, possibly, on empty return trips to Peru. The smaller of the two will also be greatly restricted in the cargo it can carry through the canal. It may therefore be most economical to operate these ships only in service to Japan. This would probably mean that several of the 50,000 to 60,000 ton ships now used for trips to Japan would be shifted to serving European ports. But the capacity of these ships is also restricted by the Panama Canal. If the new ships are more economical to operate than the present ships it may be more practical to use the new ships on trips to Europe via Cape Horn instead of shifting some of the older ships to service through the Panama Canal. The manner in which the new ships are employed will also effect the pattern of requirements for F. I. O. and bulk tonnage charters. Simple analytic models and plain arithmetic may be very useful in comparing any single practice or policy with an alternative;

however, it will be very difficult to evaluate the effects of combinations of the practices and policies on the whole shipping operation without the aid of a simulation program.

Marcona Corporation anticipates the development of new iron ore sources in Australia. This, too, would require a complete reformulation of scheduling policy. With two iron ore sources each ore contract commitment may be filled with ore from either or both of the sources. An optimizing technique such as linear programming may be useful in determining the proportion of each contract that should be filled from each of the two sources of iron. The main problem here will be in determining the cost coefficients since the real transportation costs are dependent on the ships used and on the arrangements for back haul cargo. It may be possible first to determine the distribution of the iron ore requirements between the two sources using only rough guesses at the cost parameters. These results could, then, be used to establish cargo requirements for the simulation, which would, in turn, provide a better picture of which ships would be used for each commitment and what back-haul cargo will be handled. This information would permit a better estimation of the cost coefficients in the linear programming problem so that the entire cycle may be iterated again. If the problem were properly formulated it would be hoped that the results would converge to some sort of optimum allocation of iron ore from the two sources.

In this iterative procedure above each run of the simulation would require all four phases (pages 79-82) involved in using the simulation. In Phase I the initial determination of policies to be used, another linear programming model similar to the one reported by Skeele (1963) may provide excellent guidance in selecting good scheduling policies. Skeele points out that:

> "Timing, or the random position of the optimum vessel for a certain requirement at the time it is needed often prevents us from making optimum scheduling assignments. The value of LP is limited to situations where there is actually a choice; and in many cases the importance of timing is so great that in effect, only one ship is available for a given requirement at the proper time."

The implications of the timing problem will emerge immediately in the results of the Industrial Fleet Simulation.

In ocean bulk cargo shipping, the trend is toward ever larger ships. As another example of a possible application consider the following hypothetical situation. Suppose Marcona Corporation were considering replacement of several of its smaller ships with three larger, new ships equipped with modern on-board, ore discharging equipment. They wish to determin whether such an action is a sound investment and, if so, which ships, and how many should be replaced. The yearly cargo hauling capability of the three new ships can be easily compared with the capabilities of any given set of presently used ships if the manner in which the new ships would be used is known. But how will they be used? The modern ore discharging equipment suggests that multiple port discharges, or discharging of ore into lighters, at ports with restricted harbors may become practical in places where it has not previously been done. Add to these considerations the problems of passing the larger new ships through the Panama Canal and analytic methods become impractical for evaluating the overall effects a particular decision will have. Here again, the Industrial Fleet Simulation would be highly useful in evaluating the various alternatives even after a tentative decision has been made.

The several applications suggested here represent only a sample of the host of industrial shipping problems which await study and solution. The computer and the field of operations research are newer to the shipping industry than to most industries. As more is learned about the shipping operations, analysts will better be able to formulate problems clearly so that they may be incorporated in a simulation routine. Hopefully the use of simulation will speed the development of more comprehensive analytic models.

Conclusions Concerning the Use of the Industrial Fleet Simulation

The cost of developing and using a realistic, working simulation of industrial fleet operations will, by some standards, be high. But, in comparison with the cost of purchasing or chartering and operating large ocean-going ships, the cost of computer simulation is very small. Matson Navigation Company and the United States Maritime Administration have both developed simulations of ocean liner services and have reported very favorable results. The first effort toward development of an Industrial Fleet Simulation promises equally favorable results in the simulation of bulk cargo ocean shipping. Many problems remain to be solved before a realistic simulation is obtained but these problems are primarily problems of definition and computer programming. They should be no more difficult than problems already solved in the simulation of liner service.

Learning to use the simulation as it is developed is more of a problem. The efficient development and use of the simulation will depend on close teamwork between computer programmers, operations analysts, and shipping managers who have a thorough knowledge of the operation being simulated.

Theoretically the Industrial Fleet Simulation should lead to its own destruction, since its purpose is ultimately to aid in development of analytic techniques which will eliminate the need for the trial and error approach embodied in the simulation. Practically this may never happen but the simulation effort should itself be continually re-evaluated to insure that it has not outlived its usefulness. The present development of the Industrial Fleet Simulation should be continued at least to a point where the programs are sufficiently complete to begin studying real problems. If at that time or any time thereafter it appears that the simulation will not have continuing value as a decision-making tool, it can be discarded. The information and understanding of the operations, which were gained in the effort, will undoubtedly have justified the expense.

The general approach to bulk cargo shipping and to the simulation of such shipping, as presented in this thesis, can be generalized for use on any form of non-scheduled or varied schedule cargo handling where only one class of cargo is handled. Such operations include tank truck fleets and chartered buses as well as many forms of ocean shipping. If several classes of cargo, requiring different types of storage space, must be considered and if cargo requirements must be generated stochastically, then some of the techniques and methods used in the MARAD

Fleet Simulator would also be needed. In general, simulation may be profitably employed in studying scheduling of any transportation operation with complicating factors that prevent analytic solution.

Summary

This thesis has been written with the anticipation that it will be only the first of several papers developing the problems of scheduling industrial ocean shipping. It has presented the broader aspects of the problem and begun a more detailed analysis of the variables and parameters of ship scheduling. The first version of the Scheduling Routine described in Chapter Three was intended as a start in the right direction. It has led to a better appreciation of the requirements of the entire simulation and to an understanding of some of its possible applications. A start has been made!

APPENDIX A

GLOSSARY OF SHIPPING TERMS

1. Charter. A charter or charter party is a contract for the use of an entire vessel or of its cargo carrying capacity. It is subject to the basic requirements of contract law.

1a. Bulk tonnage charter. A bulk tonnage charter is a contract between a ship owner and a shipper for the delivery of a specified number of tons of bulk cargo. The contract specifies the ship to be used, the number of tons and nature of the bulk cargo, the destination and origin ports, a dollar/ton freight rate or total cost and possibly a date by which the entire cargo must be delivered.

1b. F. I. O. (Free In and Out) Charter. The F. I. O. charter is a contract between a ship owner and shipper for one voyage of a specific ship. The contract specifies the origin destination and date of the voyage and a dollars/ton freight rate.

1c. Time charter. A time charter is a contract for the use of the cargo carrying capacity of a ship over a specified period of time. The period of a time charter usually extends over a full year or more.

2. Deadweight Tonnage. The deadweight tonnage of a ship represents the actual weight of cargo which can be carried when the ship is fully loaded to maximum displacement. It is the difference between the maximum displacement and the displacement when the ship has a full

complement of crewmen, full equipment and provisions, but no fuel or cargo.

3. <u>Demurrage.</u> Demurrage is a payment to a shipowner for holding a ship idle in port beyond limits specified in the charter party.

4. <u>Dockage.</u> Dockage is a charge for the use of a pier by a ship operator. It is usually based on the tonnage of the ship.

5. <u>Wharfage.</u> Wharfage is a charge for the use of terminal facilities for moving cargo and is usually based on the amount of cargo handled.

Note: A more detailed discussion of each of these terms is given by McDowell and Gibbs (1954).

APPENDIX B

SAMPLE OUTPUT

The data presented in Table 5 is a sample of the output of the Accounting and Editing Routine. It was extracted from the chronological output of the Scheduling Routine; it partially describes the manner in which the cargo requirements were handled for Trips 6 and 8. The data for these two trips are representative of the data for the other cargo trips and are sufficient to illustrate the results.

The sixteen ships shown in Table 3 (page 48) were used in this simulation run and the scheduling policies described in Chapter 3 (page 51) were programmed into the Scheduling Routine. The input data consisted of 31 cargo requirements for Trip 6, totaling 1,650,000 tons, and 26 cargo requirements for Trip 8, totaling 1,265,000. For Trips 7, 12, 13, 14, 16 and 17 there was a total of 4,035,000 tons of cargo. This made a grand total of 6,950,000 tons. The individual cargo requirements ranged from 20 thousand tons to 150 thousand tons with most falling between 30 and 60 thousand tons. The delivery "late dates" were distributed throughout the 360 day simulation period quite arbitrarily. The number of days between the "early date" and the "late date" of each requirement was made to be roughly proportional to the number of tons in the requirement.

The total tonnage of all the cargo requirements for all trips was not sufficient to utilize the full hauling capability of sixteen ships for 360 days. Because of this most of the ships were placed in lay-up (Trip 20) before the end of the simulation period. If a delay term (see page 69) were added to the travel times and ship maintenance requirements (see page 68) were included in the scheduling, then the ships would probably have been fully utilized. Nevertheless, the problem of timing becomes evident since a number of cargo parcels were delivered after the specified late dates.

In Table 5 all figures in the TONS column represent thousands of tons. The horizontal lines drawn through columns (1), (2), (3) and (4) divide the list of parcels into requirements which were specified as input. For example, near the beginning of the list for Trip 6 a requirement for 100 thousand tons, to be delivered between dates 0 and 60, was delivered in three parcels of 13, 54 and 33 thousand tons. Each cargo requirement has a unique identifying pair of dates in columns (1) and (2).

The horizontal lines drawn across columns (3), (4) and (5) divide the list into ship-loads. For example, the first three parcels delivered for Trip 6 were carried on one ship of 63 thousand tons.

Column (3) contains the delivery date for each parcel. For all but the first parcel in the list for Trip 6 the delivery date falls between the "early date" and "late date" in columns (1) and (2), respectively. This was to be expected since Trip 6 was the preferred trip for the two largest classes of ships (group 3 and 4). However, most of the parcels for Trip 8 were delivered late by the number of days shown in column (5). Before any action is taken to improve this situation, it must be known which of the late dates in column (2) represent contract deadlines and other important, inflexible requirements, since corrective action may not be necessary to satisfy late dates which have been set by The Corporation only to distribute work loads. No method for tagging significant late dates was incorporated in the first program. If it is assumed, for now, that it is desirable to satisfy all late dates, then columns (4) and (5) provide a basis for determining the requirements for <u>additional</u> shipping on Trip 8. Going down column (5) an additional ship is needed at each point where the number of days late makes a "significant" increase. Determining good criteria for stating specific requirements will require some study. For now, assume that it is decided that the shipments indicated by arrows to the right of column (6) are to be handled by other additional shipping. If these cargoes are handled by other ships then the remaining cargo may be shifted forward in time. The cargo for Trip 8 would then be handled as shown in Table 6. Since there is still some late cargo, one more additional ship might still be desirable.

The additional ships for Trip 8 might be obtained on F. I. O. charters or they might be owned ships taken from service on other trips. For example, if sufficient F. I. O. charters were not available at the required times it may be possible to take an owned or time chartered ship from Trip 6. Table 5 indicates that Trip 6 cargoes were delivered well within the required periods of delivery.

As was indicated in Chapter Three (page 40), the manipulations necessary to select and schedule F. I. O. chartered ships and to adjust the schedules of owned and time chartered ships will eventually be performed by the Scheduling Routine. This operation has not yet been included in the Scheduling Routine; further study of the availability and use of F. I. O. charters will be required before this portion of the simulation can be completed.

Table 5

SAMPLE OUTPUT

Cargo Handled For Trip 6

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late
0	20	26	20	6
10	40	26	30	
0	60	26	13	
0	60	30	54	
0	60	31	33	
20	60	31	30	
20	60	36	10	
30	65	36	20	
20	75	36	35	
20	75	42	25	
30	80	42	28	
30	80	46	12	
30	110	46	36	
30	110	80	54	
30	110	88	10	
50	120	88	30	
60	120	88	25	
60	120	91	45	
70	130	91	20	
80	135	91	01	
80	135	122	39	
100	150	122	24	
100	150	123	36	
100	150	123	20	
100	170	123	10	
100	170	140	40	
120	175	140	25	
120	175	141	66	
120	175	147	9	
130	180	147	30	
140	220	147	15	
150	200	157	56	
150	200	158	14	
140	220	158	39	
140	220	160	36	
180	220	160	27	
180	220	188	13	
200	260	188	50	
200	260	190	10	

Table 5--Continued

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late	(6) Delivery Number
160	270	190	56		
160	270	209	65		
160	270	208	29		
180	280	208	20		
200	290	208	17		
200	290	240	43		
240	300	240	23		
240	300	249	17		
240	310	249	39		
240	310	261	21		
260	340	261	44		
270	330	283	50		
260	340	283	13		
260	340	290	43		
290	350	290	20		
300	350	311	40		
300	360	311	20		

Cargo Handled For Trip 8

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late	(6) Delivery Number
0	40	15	40		0
0	50	20	30		1
10	55	20	13		
10	55	80	7	25	
20	60	80	20	20	2
20	80	80	19		
20	80	85	46	5	3
20	80	85	35	5	4
30	90	85	18		
50	100	125	30	25	5
50	100	137	30	37	6
70	110	197	46	87	7
50	150	211	47	61	8
50	150	225	46	75	9
50	150	234	7	84	
100	160	234	20	74	10
110	170	234	13	64	
110	170	238	27	68	11
130	190	238	16	48	
130	190	245	24	55	12

Table 5--Continued

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late	(6) Delivery Number
150	200	245	20	45	12
170	200	245	20	45	13
170	210	245	33	35	
170	210	249	7	39	14
160	220	249	27	29	
160	220	248	43	28	15
160	220	249	10	29	16
190	230	249	33	19	
190	230	271	17	41	17
190	240	271	26	31	
190	240	299	52	59	18
190	240	310	22	70	19
190	250	310	8	60	
190	250	320	12	70	20
210	260	320	41	60	
210	260	320	34	60	21
215	280	320	12	40	
215	280	324	38	44	22
260	290	324	14	34	
260	290	327	16	37	23
230	300	327	35	27	
230	300	327	25	27	24
300	350	327	28		
300	350	345	32		25
290	360	345	21		
290	360	347	47		26
290	360	348	12		27
310	360	348	34		
310	360		6	Undelivered	

Table 6

TRIP 8 CARGO DELIVERIES WITH
ADDITIONAL SHIPPING INCLUDED

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late	(6) Delivery Number
0	40	15	40		0
0	50	20	30		1
10	55	20	13		
10	55	55	7		
20	60	55	20		F.I.O.
20	80	55	19		
20	80	80	46		2
50	100	85	30		3
70	110	85	16		
70	110	85	11		4
50	150	85	42		
20	80	80	35		
30	90	80	18		F.I.O.
50	100	100	30		
70	110	100	23		F.I.O.
50	150	125	12		5
100	160	125	18		
110	170	137	30		6
130	190	197	40	7	7
150	200	197	6		
150	200	211	14	11	8
170	200	211	20	11	
170	210	211	13	1	
160	220	220	10		
190	230	220	33		F.I.O.
170	210	225	27	15	9
160	220	225	19	5	
160	220	234	40	14	10
160	220	238	11	18	11
190	230	238	17	8	
190	240	238	15		
190	240	245	33	5	12
190	250	245	11		
190	250	245	9		13
210	260	245	44		
210	260	249	31		14
215	280	249	3		
215	280	248	43		15
230	300	249	43		16
260	290	271	30		17
230	300	271	13		

Table 6--Continued

(1) Early Date	(2) Late Date	(3) Del. Date	(4) (1000) Tons	(5) Days Late	(6) Delivery Number
290	360	299	52		18
300	350	310	30		19
300	350	320	30		20
290	260	320	23		
290	360	320	5		21
310	360	320	40		

REFERENCES

Datz, I. M., Fixman, C. M., Friedberg, A. W., and Lewinson, V. A., (1964), "A Description of the Maritime Administration Mathematical Simulation of Ship Operations", The Society of Naval Architects and Marine Engineers, Paper No. 10 presented at Annual Meeting, New York, New York, November 12-13.

Gass, Saul I., (1964), Linear Programming Methods and Application, McGraw-Hill Book Company, New York, pp. 193-214.

Henry, G., (1965), Ocean Services, Inc., San Francisco, personal correspondence.

Markowitz, Henry M., Hausner, Bernard, and Karr, Herbert W., (1963), SIMSCRIPT- A simulation Programming Language, The Rand Corporation, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

McDowell, Carl E. and Gibbs, Helen M. (1954), Ocean Transportation, McGraw-Hill Book Co., New York, Chapter 9.

Roth, William M., (1957) "The Problem of American Shipping--New Questions and Old Answers," Operations Research, Vol. 5, No. 1, pp. 104-110.

Skeele, Robert B., (1963), "Analysing Ship Scheduling Problems by Computer," Shipping World, April 10, London.

User Manual for the MARAD Fleet Operations Simulation, (1964), Vol. I., General Description, Developed for the U. S. Maritime Administration by Arther D. Little, Inc., distributed by Clearing House for Federal Scientific and Technical Information, Washington D. C.

Weldon, Foster L., (1959), "Operational Simulation of a Freighter Fleet," Research Techniques in Maritime Transportation, Nat, Acad. of Sci.-Nat. Research Council, Pub. 720, Washington D. C., pp. 21-27.