February 19, 1973

To the Graduate Council:

I am submitting herewith a thesis written by Jimmy Bruce Whitchurch entitled "Optimization of an Alumina Distribution System." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor for
Graduate Studies and Research

OPTIMIZATION OF AN ALUMINA DISTRIBUTION SYSTEM

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Jimmy Bruce Whitchurch

March 1973

ABSTRACT

The purpose of this study was to constructively examine and attempt to optimize the procedures and parameters involved in the distribution of alumina from six alumina refining plants to ten aluminum smelting plants. The overall objective was to minimize total costs for the system by optimizing the balance of resources.

An in-depth evaluation of the system's characteristics and scope was made to identify impinging variables and determine the tactical and strategic needs. Attention was then focussed on developing and testing algorithms to improve the scheduling and inventory control functions, and the handling and storage facility configuration. Various operations research, computer based, and statistical techniques were employed in this optimization study.

Considerable variation in the elements of the system associated with transporting of alumina by ocean freighter was found. Efforts were concentrated on minimizing these variations and their impact on demurrage costs and inventory fluctuations to avoid a major capital expenditure for more storage capacity. A simulation study showed that the expenditure can be avoided by changing the supply sources and using the scheduling and inventory control algorithms developed. Revisions to safety stock levels and loading equipment were found to be necessary.

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CHAPTER I

INTRODUCTION

Explanation and Scope of the System

The various stages from the mines to metal involved in producing one pound of aluminum is shown on Figure 1. The timely and economical movement of alumina from the refining process to the smelting process is an important stage of this total system. This thesis deals with an examination of and attempt to optimize the procedures and parameters involved in this movement.

The Aluminum Company of America has six refining plants which regularly furnish alumina to ten smelting plants in the United States and Mexico. These shipments which total approximately three million tons per year, are scheduled by the Raw Materials Coordinator stationed in the corporate central office.

Three of the six refineries are located in the United States whereas the other three are in Australia, Suriname and Jamiaca near abundant bauxite supplies. Approximately 40 percent of the total alumina supplied to the United States smelters is being shipped from these three foreign locations and must therefore be shipped by ocean freighter.

The matrix on Table 1 shows the various transportation modes available for each origin-destination cell. Those combinations which can be ruled out initially by intuition because of proximity of supply-demand points or differences in transportation rates for the various modes are circled. Potential routings requiring more than two modes of

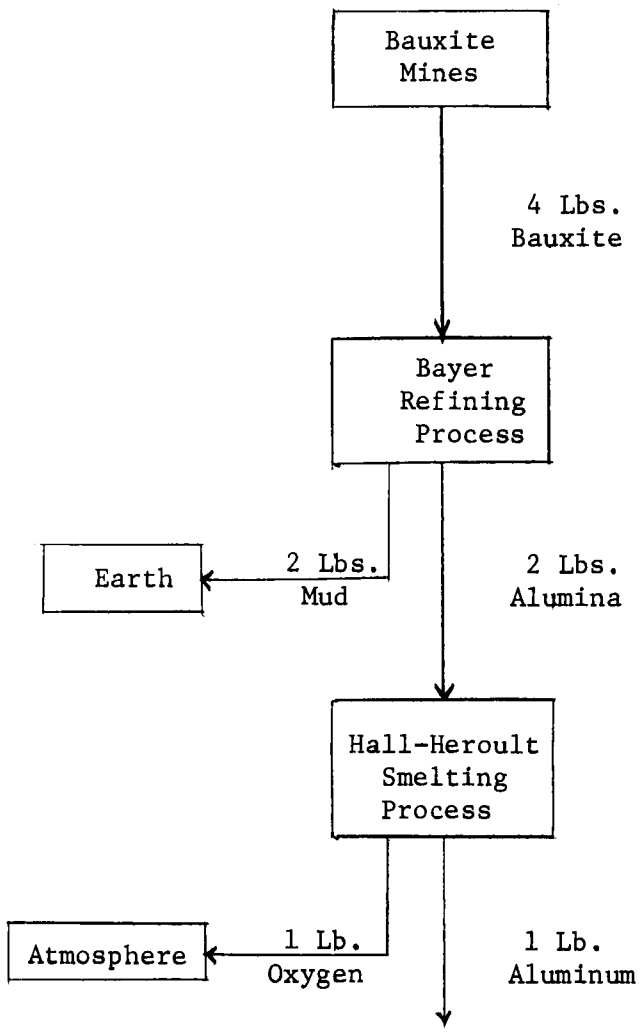


Figure 1. Flow chart for the process of producing aluminum.

TABLE 1

MATRIX OF AVAILABLE TRANSPORTATION MODES

Origins	Destinations D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
S1	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship-Rail Ship-Barge	Ship-Rail
S2	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship-Rail Ship-Barge	Ship-Rail
S3	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship	Ship-Rail	Ship-Rail	Ship-Rail	Ship-Rail Ship-Barge	Ship-Rail
S4	Ship Rail	Ship-Rail Rail	Ship-Rail Rail	Ship-Rail Rail	Rail	Rail	Rail	Rail	Barge Rail	Rail
S5	Ship Rail	Ship-Rail Rail	Ship-Rail Rail	Ship-Rail Rail	Barge Rail	Rail	Rail	Rail	Barge Rail	Rail
S6	Rail	Rail	Rail	Rail	Rail	Rail	Rail	Rail	Rail	Rail

transportation per trip were judged impractical after an initial investigation and therefore were not listed.

Changing Parameters Necessitate a Study

A number of driving forces during the past year have caused the alumina distribution system to become more complex and dynamic. These forces included:

1. Production of alumina recently began at the new plant in Jamaica.
2. A number of new products and processes at particular smelting plants required specific types of alumina. This meant that certain suppliers should supply certain plants, and that in some cases aluminas from different suppliers should not be mixed together. The tradeoff of overriding these constraints with extra operating costs or profit margin from lost business versus extra transportation costs needed to be determined.
3. A proposal to relocate production of a new product requiring a special alumina and hence an imposed demand constraint needed to be evaluated.
4. The installation of new docks, storage tanks and alumina handling equipment for ship and barge loading and unloading at strategic domestic locations had been proposed and needed to be evaluated.

This recent flurry of changes and amplification of variables emphasized the need not only for a one time optimization study of the

system but also a viable alumina distribution model for closer monitoring of inventories and shipments on a continuing basis. A more efficient and effective method of scheduling and controlling inventories than the time consuming iterative procedure the Raw Materials Coordinator was manually using was needed.

General Discussion of Approach

Because of the magnitude of the system and other priorities, it was necessary to employ a piecemeal or "crisis response" approach. Such an attack is not uncommon in today's business world, where everything is one big tradeoff and those seeking to control it must react accordingly. The inherent advantages of a global attack on all segments or subsystems of the system simultaneously to capture the interrelationships between variables are quite apparent. However, this Uptopian approach must often give way to the expeditious piecemeal approach to meet rapidly changing priorities.

Special attention was given to the interconnections between parts of the system and the total system, and also to the various time horizons to be considered. Consideration was initially given to structuring the problem as a multi-stage, mixed integer linear program using the decomposition principle; however, it soon became apparent that the linearity and combinational assumptions inherent with this approach were not realistic.

Considerable time was spent in seeking to develop an optimal scheduling and inventory control algorithm. Not only was a cosmopolitan examination made of available literature, but a series of models employing

linear programming, simulation, algebraic and other mathematical techniques were built and tested. In the final analysis, it was concluded that each of the early solutions had shortcomings since the inherent assumptions of the technique used didn't give a true representation of the real problem. Only the final solution which borrowed the best from previous solutions gave near optimal results.

During the formulation stage of the problem it became quite apparent that the greatest variability and potential for improvement existed in that portion of the distribution system involving movement by ocean freighters. Consequently, greater emphasis was given to this area in the study. Particular attention was given to the scheduling and facility needs at receiving port R1 where the alumina is unloaded from the ships into four large dockside tanks and then subsequently transshipped to the three smelting plants D1, D2 and D3.

In summary, this paper describes the step by step approach used in solving a classical optimization problem in industry. The objective was to achieve an optimum balance of resources in controlling costs for the summation of transportation costs, inventory holding costs, smelting plant operating costs, and alumina storage and handling facility costs.

Synopsis of Study

Chapter II is devoted to defining the problem. A broad evaluation was made of the scope and parameters of the system to identify impinging variables and determine the tactical and strategic needs of the system. The current system under existing conditions was analyzed in-depth using regression and statistical analyses to establish a base

for improvement. Considerable attention was given to this crucial step of formulating the problem not only initially but through periodic re-examination of the problem and objectives during the later phases.

Chapter III deals with the macro considerations for optimizing the distribution system. This chapter is devoted to economic tradeoffs between distribution costs, inventory costs, special alumina requirements, stock out costs, additional handling and storage facilities, and refining plant operating costs.

After macro parameters have been established, then alternative solutions and scheduling procedures for improving the inventory control system on the micro level are presented in Chapter IV.

In Chapter V the various alternate solutions are evaluated and results from each are compared to the present system. Implementation of the final solutions and scheduling procedures are discussed.

CHAPTER II

FORMULATION OF THE PROBLEM

Alumina Supply Availability

Shipments of alumina to sales and foreign customers are made from the refining plants in addition to supplying the ten regular smelting plant customers. Current and projected metric tons available for domestic smelters were determined by deducting any sales or foreign commitments from the current alumina production levels.

The new foreign refining plant, S3, has been limited in production for several months; however, no history of ship travel time distributions to various demand points is available yet.

Storage at Refining Plants

The alumina is conveyed to large storage tanks as it is produced. Maximum storage capacity in terms of tons, days of production, and number of average shiploads, barge loads or rail car loads was determined for each plant. Physical inventories are measured and reported to the corporate office monthly.

Alumina refining is a process type operation which can not be economically interrupted for short durations to adjust inventories. The loading of ships or other transport modes must therefore be scheduled to maintain inventory levels below tank capacity.

Modes of Transportation

The available modes of transportation for each supply-demand

combination as shown in Table 1 on page 3 were determined based on existing loading and unloading facilities and carrier routes.

Load Size

It was determined that demand is expressed in discrete quantities to correspond to the fixed quantity loads of each type carrier. Coefficients of variation in load size were found to be less than 2.0 percent for rail cars and 4.2 percent for barges. This limited variation permitted the use of a constant discrete quantity for these types of carriers. On the other hand, considerable variation in load size between ships was found as shown by the historical frequency distribution on Figure 2. A statistical analysis of this distribution by supplier to determine means, variances and standard deviations is shown on Table 2. This analysis is based on normal distributions and the load size distributions for each supplier being independent of each other, meaning the coefficient of correlation is zero. The hypothesis that the given frequency distributions from each supplier could be approximated by the normal distribution was verified by plotting the cumulative relative frequencies on probability graph paper and observing that the plotted points lie close to a straight line. These graphs are shown as Figures 11 and 12 in the Appendix.

Replenishment Time

The average travel time for each route and method of travel was established based on historical data. It was found that approximately 100,000 tons or 3 percent of annual shipments was constantly held as

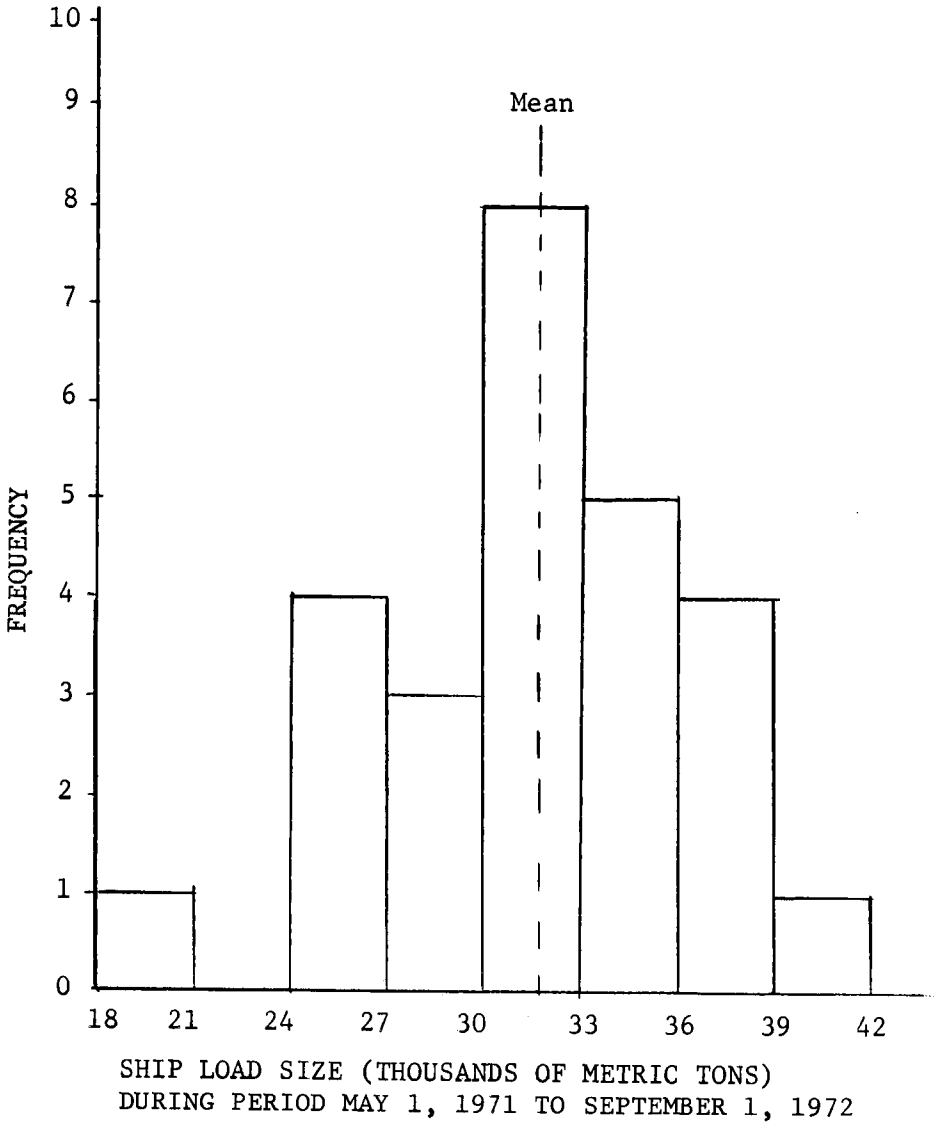


Figure 2. Frequency distribution analysis of shipload size.

TABLE 2

STATISTICAL ANALYSIS OF SHIP LOAD SIZE

Ship Load Size (Thousand Metric Tons)	From S1			From S2			Total Shipments	
	P(X)	X·P(X)	$(X-\mu_A)^2 \cdot P(X)$	P(X)	X·P(X)	$(X-\mu_S)^2 \cdot P(X)$	P(X)	$X \cdot P(X_T)$
18 - 21				.06	1.17	14.04	.038	.74
21 - 24								
24 - 27	.10	2.55	8.65	.18	4.60	15.57	.142	3.62
27 - 30				.18	5.13	7.14	.114	3.25
30 - 33	.10	3.15	1.09	.42	13.20	4.57	.326	10.27
33 - 36	.40	13.80	.04	.10	3.45	.01	.200	6.90
36 - 39	.30	11.25	2.19	.06	2.25	.44	.142	5.32
39 - 42	.10	4.05	3.25	____	____	____	.038	1.54
Σ	1.00	$\mu_A = 34.80$	$\sigma_A^2 = 15.22$	1.00	$\mu_S = 29.80$	$\sigma_S^2 = 41.77$	1.000	$\mu_T = 31.64$
Standard Deviation			$\sigma_A = 3.90$			$\sigma_S = 6.48$		

Mean (Total)= $\mu_T = \Sigma [X \cdot P(X_T)] = 31.64$

Standard Deviation (Total)= $\sigma_T = 7.55$

Variance (Total)= $\sigma_T^2 = \sigma_A^2 + \sigma_S^2 = 56.99$

movement inventories as a result of the transit time required between the refining and smelting plants.

Replenishment time from suppliers shipping by rail and barge were found to have minimum variations and were therefore assumed to be constant. On the other hand, it was learned that an inherent characteristic of ocean freighters is considerable variation in voyage time. Consequently, a range referred to as "lay days" in the mariner's world is used for scheduling departures and arrivals instead of a point estimate. To determine the reasons for and significance of this schedule variation, the voyage segments of arrival time at the alumina loading port, travel from the alumina plant origin to the smelting plant destination, and subsequent arrival time at unloading port were analyzed. Details of these analyses are discussed later on pages 19 through 23 of this chapter.

Cost of a Stockout at Smelting Plant

A stockout at a smelting plant is considered prohibitive because of the high costs of shutting down and restarting the potline. A safety stock at each plant equal to twenty-five days of consumption is the rule of thumb amount to be held as a hedge against natural or man-made delivery delays.

Inventory Control at Smelting Plants

Given the macro parameters in existence at the time governing sources and volumes of supply, demand volumes and special requirements, available facilities and modes of transportations, and safety stocks, the Raw Materials Coordinator's objective is to minimize transportation costs while maintaining inventory levels within the prescribed limits.

Inventory Levels at Smelting Plants

Physical inventory levels at each smelting plant are measured monthly and reported to the Raw Materials Coordinator. Inventory control was found to be most critical at receiving port R1 where receipts are transshipped to three smelting plants. Alumina was received by ocean freighter into this port from two and sometimes all three foreign refineries. Accumulative volumes of consumption and receipts were analyzed to assess historical patterns and effectiveness of inventory control. This twenty month analysis which is plotted on Figure 3 showed considerable variation in end-of-the-month inventories. Inventories fluctuated from the accepted safety stock level of 35 million pounds to the maximum storage capacity level of 160 million pounds.

Demurrage and Ship Unloading Time

An hourly demurrage of $42 plus .25¢ per ton unloaded, which equates to $120 per hour for the average shipload of 31,000 tons, is charged by the ship owners for any delays exceeding the allowed unloading time. The allowed unloading time is calculated by dividing the load size by an expected unloading rate of 475 tons per hour.

Minimizing the demurrage expense at receiving port R1 is a critical factor requiring control of the following four variables:

1. Ship arrivals need to be scheduled so two ships are not in port simultaneously since the port is equipped for unloading only one ship at a time.
2. Adequate storage capacity must be available in dockside tanks to accommodate a full ship load, otherwise unloading operations

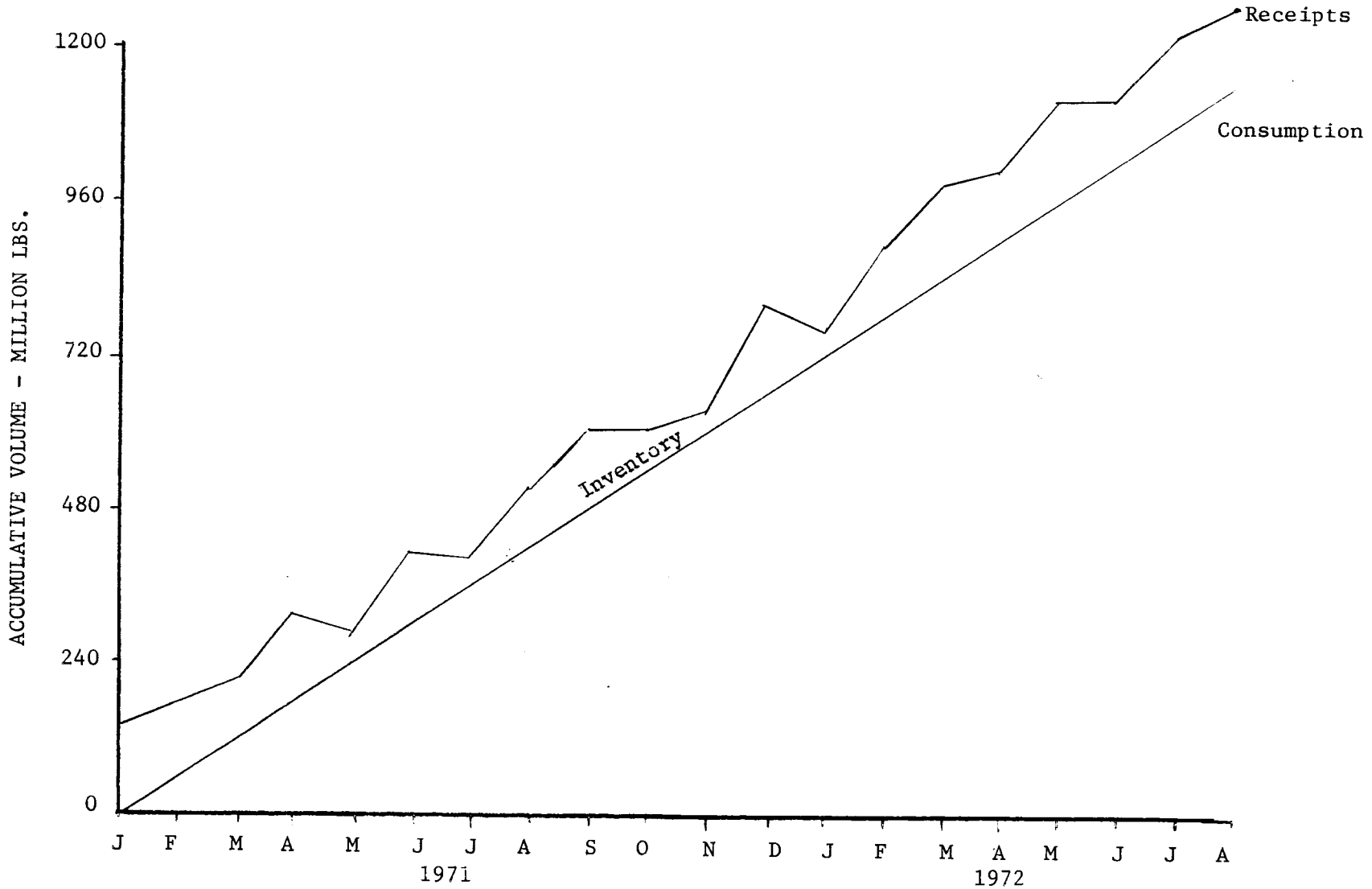


Figure 3. Historical analysis of inventories at receiving port R1.

would have to be curtailed until adequate space is available. Since this port serves as a transshipment point for three smelting plants, the balancing of inventories in the dockside tanks with inventories in each plant's tanks, as well as the loading rate of rail cars for transshipment from dockside tanks are also key considerations in keeping dockside tank capacity available.

3. Capacity of the unloading equipment should be sufficient to average 475 tons per hour after accounting for expected delays. Average unloading speed while the equipment was operating was found to be 544 tons per hour for the most recent twelve ships.
4. Delays from unloading equipment malfunctions or maintenance and the post cleanup of ships and equipment must also be accounted for in the time a ship is allowed to be in port. A historical analysis showed these delays account for 18 percent or an average of 12.7 hours per ship.

A historical distribution of ship unloading rates over the past year is shown on Figure 4. Statistical calculations showed this distribution to have a mean of 430 tons per hour and a standard deviation of 60 tons per hour.

Scheduling Procedure for Ships

The Raw Materials Coordinator's threefold challenge when scheduling alumina shipments several months in advance is:

1. maximum compliance to the most recent established macro parameters governing the supply-demand matrix;

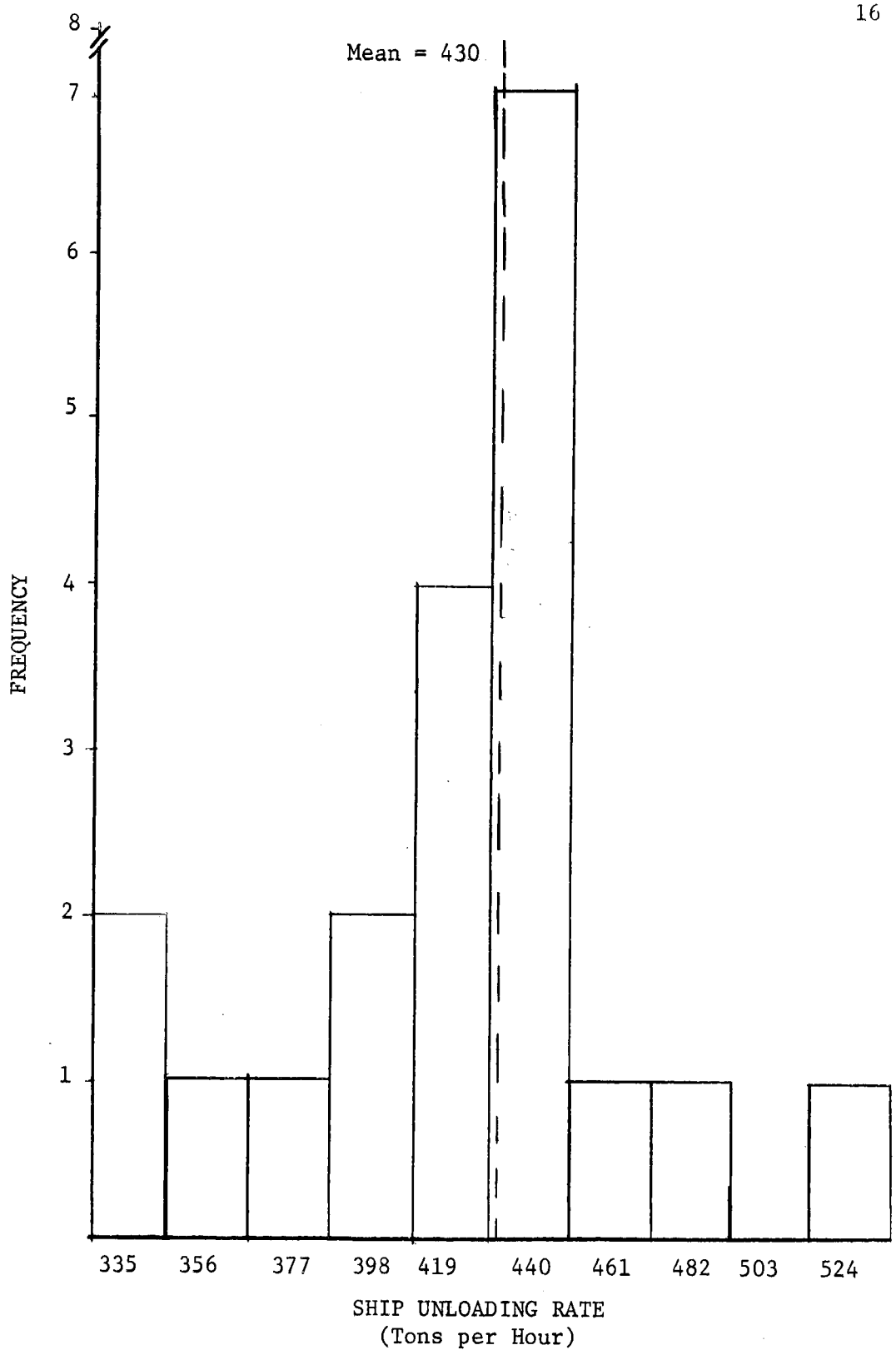


Figure 4. Ship unloading rate distribution.

2. balancing inventories to guard against stockouts and exceeding storage capacity; and
3. spacing out ship arrivals to avoid having more than one ship in port at a time.

These challenges or objectives are often conflicting and therefore require a keen judgement in establishing schedules and recognizing when they should be revised.

Based on the criteria above, ships are tentatively scheduled four to six months in advance. The first step in this scheduling process is to divide the number of tons designated in each cell of the macro supply-demand matrix for that period by the average number of tons per shipload to establish the number of shiploads for each matrix cell to be shipped in the next scheduling period. Then it becomes a matter of scheduling the departures and arrivals of each designated ship for a specific date or range of dates based on the inventory and enroute quantities at each plant, average travel time for each route and the need to avoid two ships in a port simultaneously.

Average travel time estimates of one month from S1 to R1, nineteen days from S2 to R1 and fourteen days from S3 to R1 were used for scheduling purposes.

In some cases a single point estimate of an explicit date was used in expressing either or both schedules for departure from the supply plant and arrival at the demand plant. In other cases a ten to fifteen day interval in the form of a "lay days" range was used to express either or both of the departure and arrival schedules.

The key control reports used in the scheduling procedure are:

1. A monthly activity and status report shows tons shipped for each supply-demand matrix cell with a summation and daily average for each plant, tons enroute to each smelting plant, inventory level in tons and number of day's supply at each smelting plant, unfilled storage capacity available at each smelting plant and tons consumed at each user plant.
2. A six month shipping schedule lists by vessel the origin, estimated departure time, estimated arrival time and tonnage.
3. Inventory balances are projected at the receiving port for the estimated arrival date of each ship by showing starting inventory less consumption and transshipments plus receipts over the six month period.
4. A weekly updated report projects inventory balances for each month end at the supply plants over the ensuing six month period by showing inventories minus scheduled shipments plus scheduled production.
5. A weekly report which incorporates any revisions or additions to the ship schedules and thereby updates the projected departure and arrival dates for each ship over the next four to six months is kept.

The tentative ship schedules which are established four to six months in advance are subject to revision by mutual consent between the Aluminum Company and the chartering steamship company as the need arises. The greatest revision opportunities exist in the first few months before

the scheduled voyage is chartered to a specific ship. A vessel is normally named for a scheduled voyage one to two months in advance. The several small changes for a few days normally made in the weekly update of a ship's schedule during the final month before its voyage are attributed primarily to the ship's inability to meet the schedule due to the variability associated with previous voyages. The customer seldom has an opportunity to revise schedules during this committed period.

Ship Travel Time

Ship travel times were analyzed individually for each route over the past eighteen months to determine the mean and characteristics of the variations. The key question to be answered for each route was whether travel time is dependent on some predictable or known variable such as individual ship speed, load size or the ship being late or early with respect to arriving on an appointed day. This latter dependency on schedule lateness or earliness would suggest that travel time is varied at the ship captain's discretion. A summary of the statistical analysis of ship travel times is shown on Table 3.

The following statistical inferences were drawn from this analysis concerning the travel times:

1. Mean travel times were 28.1 days for route S1-R1 and 19.3 days for foute S2-R1 compared to the one month and 19 days currently being used for scheduling purposes.
2. The range of travel times between the slowest and the fastest trips was eight days for route S1-R1 and six days for route S2-R1. The range between the means of individual ships was 5.7 days for S1-R1 and 3.3 days for S2-R1.

TABLE 3

STATISTICAL ANALYSIS OF SHIP TRAVEL TIME

	Route	
	S1-R1	S2-R1
Range	24 - 32 Days	17 - 23 Days
Mean	28.1 Days	19.3 Days
Mean for Late Ships	29.5 Days	19.2 Days
Mean for Early Ships	26.3 Days	19.5 Days
Frequency $(\frac{\text{Load Size}}{\text{Travel Time}} R > 0)$	40 Percent	50 Percent
Range by Ship $\bar{X}$	24.0-29.7 Days	17.0-20.3 Days
Range for Rated Ship Speeds	14.0-15.5 Knots	14.0-15.5 Knots

3. No relationship was found between load size and travel time for a particular ship. The correlation coefficient (R) was greater than 0 for less than 50 percent of the ships sampled, thus inferring no correlation. With this dichotomous test over half of the samples would have to have a positive coefficient to suggest a direct relationship between load size and travel time.

4. Mean travel times for S1-R1 ships that arrived at their destination late was longer than the overall mean travel time, and the mean travel times for ships that arrived early at their destination was less than the overall mean travel time. For S2-R1 ships the mean travel time for late and early ships were both approximately the same as overall mean travel time, thus indicating no correlation. There was therefore no support to the hypothesis that the ship captain exercises his discretion to go slower or faster based on whether his ship is running ahead or behind schedule.

5. By ruling out the correlations of ship travel time with load size and crew discretion, and determining that a range of six days between individual ship mean travel times was less than the range of eight days for all trips, two inferences were left. The first implication was that there must be a difference in the speed of the various ships attributed to variations in design or power source. Further investigation disclosed there was over 10 percent variation between the rated speed of individual ships.

The second implication was that approximately two-thirds of the travel time was independent of other predictable or controllable variables and occurs randomly based on the temperament of the seas and other obscure factors.

Ship Departure Times from Refining Plants

The comparison of actual departure times with scheduled departure times over the past eighteen months is shown on Table 4. This analysis revealed that 60 percent of the ships departed later than scheduled and the average ship departs from S1 plant 3.9 days later than scheduled and from S2 plants 2.4 days later than scheduled. The range of variation between actual and scheduled departure dates was found to be -10 to +17 days with the variation from supplier S2 being more severe than from S1.

Ship Arrival Times

The variation analysis between actual and scheduled arrival dates on Table 3 (page 20) reveals that 65 percent of the ships arrive at R1 port later than scheduled. The average ship from S1 arrived 1.9 days later than scheduled and from S2 2.6 days later than scheduled.

Overview of the Scheduling Criteria

The following key criteria govern the scheduling process:

1. Safety stocks must be maintained at each demand plant to avoid a costly shut down.
2. Alumina inventory levels must be balanced over the total system to assure that inventories are below the tank storage capacity at each refining and smelting plant.

TABLE 4

VARIATION ANALYSIS BETWEEN ACTUAL AND SCHEDULED DEPARTURE AND ARIVAL DATES

	From Plant S1	From Plant S2	Total
Departure Date from Supply Plant			
Average Variation	+3.9 Days (Late)	+2.4 Days (Late)	+3.0 Days (Late)
Range of Variations	-5 to +12 Days	-10 to +17 Days	-10 to +17 Days
Late (+) Occurrences	70 Percent	55 Percent	18 Percent
Early (-) Occurrences	15 Percent	20 Percent	18 Percent
On Schedule Occurrences	15 Percent	25 Percent	22 Percent
Arrival Date at Receiving Port			
Average Variation	+1.9 Days (Late)	+2.6 Days (Late)	+2.3 Days (Late)
Range of Variations	-11 to +10 Days	-7 to +15 Days	-11 to +15 Days
Late (+) Occurrences	55 Percent	70 Percent	65 Percent
Early (-) Occurrences	30 Percent	15 Percent	20 Percent
On Schedule Occurrences	15 Percent	15 Percent	15 Percent

3. Demand constraints are imposed where economically justified.

4. Demurrage charges must be paid when a carrier is delayed in loading or unloading alumina. This criteria is of major concern in scheduling ship arrivals at R1 since the unloading dock can only accommodate one ship at a time.

5. Ships must be chartered for a specific voyage with a designated "lay day" time schedule one to two months in advance. Little opportunity exists for revising schedules after a ship is named and scheduled.

6. Subject to the considerations listed as 1, 2, 3, 4 and 5 above, the objective is to minimize the transportation costs by selecting the optimum routing.

Obviously each of these criteria can not simultaneously be optimized, so the ultimate objective is to achieve a balance that gives an overall minimum cost.

CHAPTER III

OPTIMIZATION OF MACRO PARAMETERS

Supply-Demand Projections and Balances

Five year projections of production levels at each refining and smelting plant are made in a corporate plan. Shorter range projections by quarter for the next year are also made. While some of the criteria influencing the plan are difficult to quantify, the decision as to the level each plant will be operated at is primarily one of economics on a macro level. The minimum cost model for an integrated aluminum producer is derived on Table 5. It is obvious that some sub-optimization is likely to occur when seeking to minimize costs of any one subsystem.

Loading and Unloading Equipment Capabilities

Loading and unloading rates at each location are adequate to avoid demurrage costs with the exception of unloading port R1. Based on the unloading rate distribution shown on Figure 4 on page 16, only 10 percent of the ships are unloaded fast enough to avoid a demurrage charge. According to this distribution the average ship is in port six hours longer than allowed and therefore costs $720 based on the demurrage formula described on page 13. A discounted cash flow analysis disclosed that a maximum of $82,800 could be spent to reduce the port time enough to eliminate all demurrage. This economic evaluation was based on a 10 percent cost of capital, a fourteen year project life, sum-of-the years' digits method of depreciation writeoff and a 48 percent tax rate.

An investigation of potential equipment revisions that would

TABLE 5

MINIMUM COST MODEL FOR INTEGRATED ALUMINUM PRODUCER

$$C = \Sigma p_i X_i + \Sigma q_{ij} Y_{ij} + \Sigma r_j Z_j + \Sigma S_{jk} d_{jk} + \Sigma t_k e_k + \Sigma U_{km} f_{km} + \Sigma V_m g_m + \Sigma W_{mn} h_{mn}$$

C = total annual cost to be minimized.

p_i = unit cost of mining bauxite at mine i.

q_{ij} = unit cost of transporting bauxite from mine i to refinery j.

r_j = unit cost of producing alumina at refinery j.

S_{jk} = unit cost of transporting alumina from refinery j to smelter k.

t_k = unit cost of producing aluminum at smelter k.

U_{km} = unit cost of transporting aluminum from smelter k to fabricator m.

V_m = unit cost of fabricating product at fabricator m.

W_{mn} = unit cost of transporting product from fabricator m to customer n.

X_i = units per year of bauxite mined at mine i.

Y_{ij} = units per year of bauxite transported from mine i to refinery j.

Z_j = units per year of alumina produced at refinery j.

d_{jk} = units per year of alumina transported from refinery j to smelter k.

e_k = units per year of aluminum produced at smelter k.

f_{km} = units per year of aluminum transported from smelter k to fabricator m.

g_m = units per year of product fabricated at fabricator m.

h_{mn} = units per year of product transported from fabricator m to customer n.

reduce in-port time revealed that the conveying equipment for loading alumina being transshipped from the dockside tanks at port R1 to user plants D2 or D3 was unreliable and slow. This inability to remove alumina from the dockside tanks faster when the tank capacity was needed was causing some delays in unloading ships. A decision was made to replace the existing 100 ton per hour conveyor with a new 200 ton per hour conveyor at a cost considerably less than the calculated ceiling of $82,800 that could be spent to eliminate demurrage.

Minimum Transportation Costs

To identify the optimum routing yielding minimum transportation costs, a classical transportation problem structured as a computer algorithm is used. The rectangular array on Figure 5 displays how this problem is solved under the conditions that a given quantity a_i is to be shipped from each of six origins, a given quantity b_j is to be received by each of ten destinations and $\sum_{i=1}^{6} a_i = \sum_{j=1}^{10} b_j$. The array also shows the transportation cost C_{ij} of shipping one ton of alumina from each origin to each destination. The algorithm is designed to go through the iterative process of finding a solution such that the total period cost $Z = \Sigma C_{ij} X_{mn}$ is minimum.

Evaluation of Demand Constraints

Improvements in smelting operating costs or product quality can often be accomplished by using a specific type of alumina at a certain plant. Such an imposed demand constraint normally requires deviating from the routing identified by the transportation algorithm as giving

ORIGINS \ DESTINATIONS	D1	D2	D3	D4	D5	D6	D7	D8	D9	DQ	Row Totals
S1	X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	X_{14} C_{14}	X_{15} C_{15}	X_{16} C_{16}	X_{17} C_{17}	X_{18} C_{18}	X_{19} C_{19}	X_{1Q} C_{1Q}	a_1
S2	X_{21} C_{21}	X_{22} C_{22}	X_{23} C_{23}	X_{24} C_{24}	X_{25} C_{25}	X_{26} C_{26}	X_{27} C_{27}	X_{28} C_{28}	X_{29} C_{29}	X_{2Q} C_{2Q}	a_2
S3	X_{31} C_{31}	X_{32} C_{32}	X_{33} C_{33}	X_{34} C_{34}	X_{35} C_{35}	X_{36} C_{36}	X_{37} C_{37}	X_{38} C_{38}	X_{39} C_{39}	X_{3Q} C_{3Q}	a_3
S4	X_{41} C_{41}	X_{42} C_{42}	X_{43} C_{43}	X_{44} C_{44}	X_{45} C_{45}	X_{46} C_{46}	X_{47} C_{47}	X_{48} C_{48}	X_{49} C_{49}	X_{4Q} C_{4Q}	a_4
S5	X_{51} C_{51}	X_{52} C_{52}	X_{53} C_{53}	X_{54} C_{54}	X_{55} C_{55}	X_{56} C_{56}	X_{57} C_{57}	X_{58} C_{58}	X_{59} C_{59}	X_{5Q} C_{5Q}	a_5
S6	X_{61} C_{61}	X_{62} C_{62}	X_{63} C_{63}	X_{64} C_{64}	X_{65} C_{65}	X_{66} C_{66}	X_{67} C_{67}	X_{68} C_{68}	X_{69} C_{69}	X_{6Q} C_{6Q}	a_6
Column Totals	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_Q	

Figure 5. Alumina scheduling model transportation array.

minimum transportation costs. To analyze the cost tradeoffs and determine the feasibility of imposing the constraint the following procedure is used:

1. Savings in operating costs or product margin are calculated from the imposed constraint that an original r must ship to a destination s. These savings are designated as p.
2. The transportation algorithm is rerun with the imposed quantity blocked out of a_r and b_s. Total transportation cost, $Z_q = \Sigma C_{ij} X_{mn}$, for the system without this blocked out quantity is determined.
3. Total period costs associated with the imposed constraint are manually calculated using the following formula:

$$Z_v = Z_q - p + C_{rs} (X_{rs})$$

4. If the minimum transportation cost Z is greater than Z_v then the constraint is accepted on the basis of yielding minimum overall costs.

The mixing or changing of types of alumina is recognized as a detriment to smelting plant operating performance; however, the effect could not be quantified. This factor is one that should be dealt with on a judgemental basis after calculating the cost of avoiding it.

Safety Stock Versus Stock Out Tradeoff

Costs of shutting down and restarting a smelting plant as a result of running out of alumina versus the holding costs of a safety stock inventory were analyzed. Based on this analysis the indifference curve shown on Figure 6 was constructed. This curve shows that the current

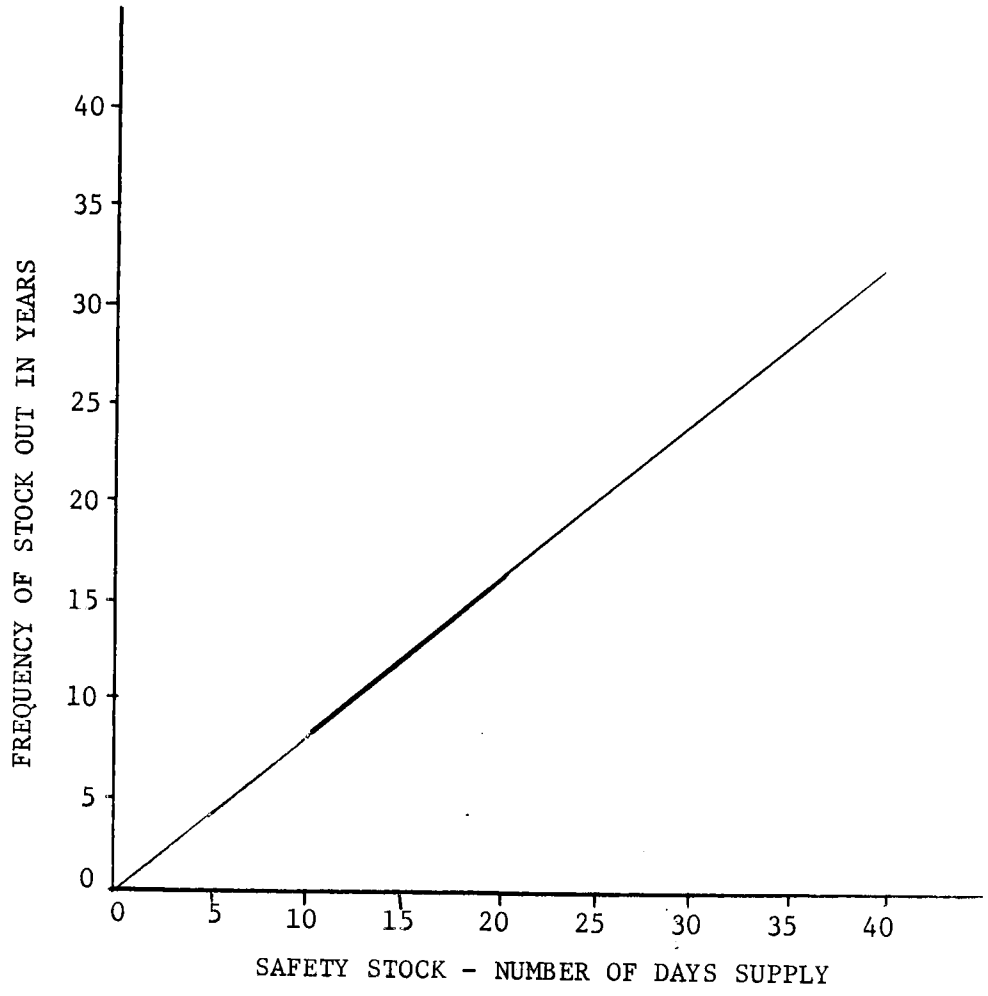


Figure 6. Safety stock indifference curve.

goal of having a twenty-five day safety stock at each plant is justified if it prevents a shutdown due to stockout occurring at least once every twenty years.

A sensitivity analysis based on the replenishment times and variations in the combined inventories of the West Coast system, comprised of plants D1, D2 and D3 and port R1, was made to assess the probability of a stock out. During the last eighteen months the maximum tardiness for 34 ship arrivals at port R1 was 15 days. There were two occasions during this period when the inventory at plants D1, D2 and D3 were low enough that such a delay may have resulted in a stockout. On the basis that this history is representative and the tardiness and minimum inventories are mutually exclusive of each other, then the probability of a stock out at these plants with a 15 day safety stock is: $p = 1/34 \times 2/34 = .00174$ or every 580 ships. Based on a frequency of 23 ships per year this analysis would indicate a stockout would be expected only once every twenty-five years with a 15 day safety stock.

The replenishment time mean and distribution and the cost of a stock out should be the chief criteria for setting different safety stocks for each plant. In addition to this stocking allowance for fluctuating inventories consideration must also be given to anticipatory inventories which are justified for spot sales, capacity problems and production smoothing.

Minimum stocks were calculated for each smelting plant on Table 6 based on the minimum practical replenishment allowances without any allowance for prolonged interruptions in supply source or transportation systems. These calculated safety stocks are therefore considered minimum

TABLE 6

MINIMUM STOCK CALCULATIONS FOR SMELTING PLANTS

Demand Plant	Nearest Regular Supplier	Regular Carrier	Number of Days: Travel Time (T)	Travel Variation Allowance (V) = (2σ)	Replenishing Constant (C)	Minimum Stock (M)
D1	S3	Ship	14.0	2.8	6.0	22.8
D2	S3	Ship-Rail	16.0	3.6	6.0	25.5
D3	S3	Ship-Rail	16.0	3.5	6.0	26.5
D4	S2	Ship-Rail	8.0	2.0	6.0	16.0
D5	S4	Rail	1.0	0.0	5.0	6.0
D6	S4	Rail	5.0	1.5	5.0	11.5
D7	S5	Rail	8.0	1.8	5.0	14.8
D8	S6	Rail	7.0	1.8	5.0	13.8
D9	S5	Barge	10.0	2.4	5.0	17.8
D10	S5	Rail	10.0	2.4	5.0	17.8

$M = T + V + C$

Legend: M = Minimum allowable stock in days of consumption.

T = Mean travel days using nearest regular supplier and regular carrier.

V = Travel time variation allowance equal to two standard deviations to cover 97.5 percent of cases.

C = Replenishing constant to cover receiving order, scheduling shipment, loading and unloading time.

levels and should never be undercut except under the most adverse conditions. These minimum stock calculations are based on rather limited data on lead times by rail and therefore need to be refined when more information is available.

Storage Capacity

Four dockside tanks are currently available at receiving port R1 in addition to the storage tanks at the smelting plants D1, D2 and D3 where alumina is transshipped from the receiving dock. A reduction in effective storage capacity due to a process change at one of the plants, the likelihood of having to receive alumina from three suppliers instead of two, and increased consumption rates forced the possible installation of a fifth dockside tank to be considered. Projected costs of this tank with attendant conveyors was $1,000,000. The potential penalty of not having this tank was reduced inventory flexibility and consequently a stock out or increased demurrage costs as a result of ships having to wait until adequate tank capacity is available to unload. Obviously this potential expenditure gave considerable emphasis to minimizing the variation in time between ship arrivals and inventories. The discounted cash flow net present value calculations on pages 78 and 79 in the Appendix show that $165,000 or 50 demurrage days must be saved annually over the next twenty years to justify installation of the tank.

Transportation, Demurrage, Inventory Cost Tradeoffs

A comparative analysis of the various cost factors verified that transportation is the overriding factor whether the carrier is ship, rail car or barge. Rather significant sacrifices in inventory and

demurrage costs are justified to minimize transportation costs.

Consideration was given to reducing the shipment size to minimize the inventory and demurrage costs. Figure 7 shows that the lower unit costs for transporting large shipments clearly dictate that shipments be as large as possible to achieve minimum overall costs.

Dynamics of the System

The numerous changes and possibilities in sources of supply, storage capacity and demand constraints dictated that the system be viewed in a dynamic state to capture the overall effect of interacting variables. The most pertinent consideration in balancing the system was whether an additional storage tank was needed at port R1. The decision matrix on Table 7 was constructed as a means to lay out and consider the available combinations of decisions and events and then rank the relative value of expected outcomes at R1. This parameter sensitivity analysis indicated that the outcomes for each of these potential events needed to be evaluated in more detail, and also that the source of supply for R1, which is dynamically interrelated to the total alumina distribution system, is the major criteria affecting outcomes.

Simulation Model

Once the alternate events to be considered in the evaluating of R1 storage requirements had been identified in the decision matrix, a model was needed to simulate the effect on the system of each event. Since a number of the key variables had recursion relationships or could only be expressed as a distribution, a Monte Carlo simulation computer program was chosen to solve the problem. The model was programmed on a

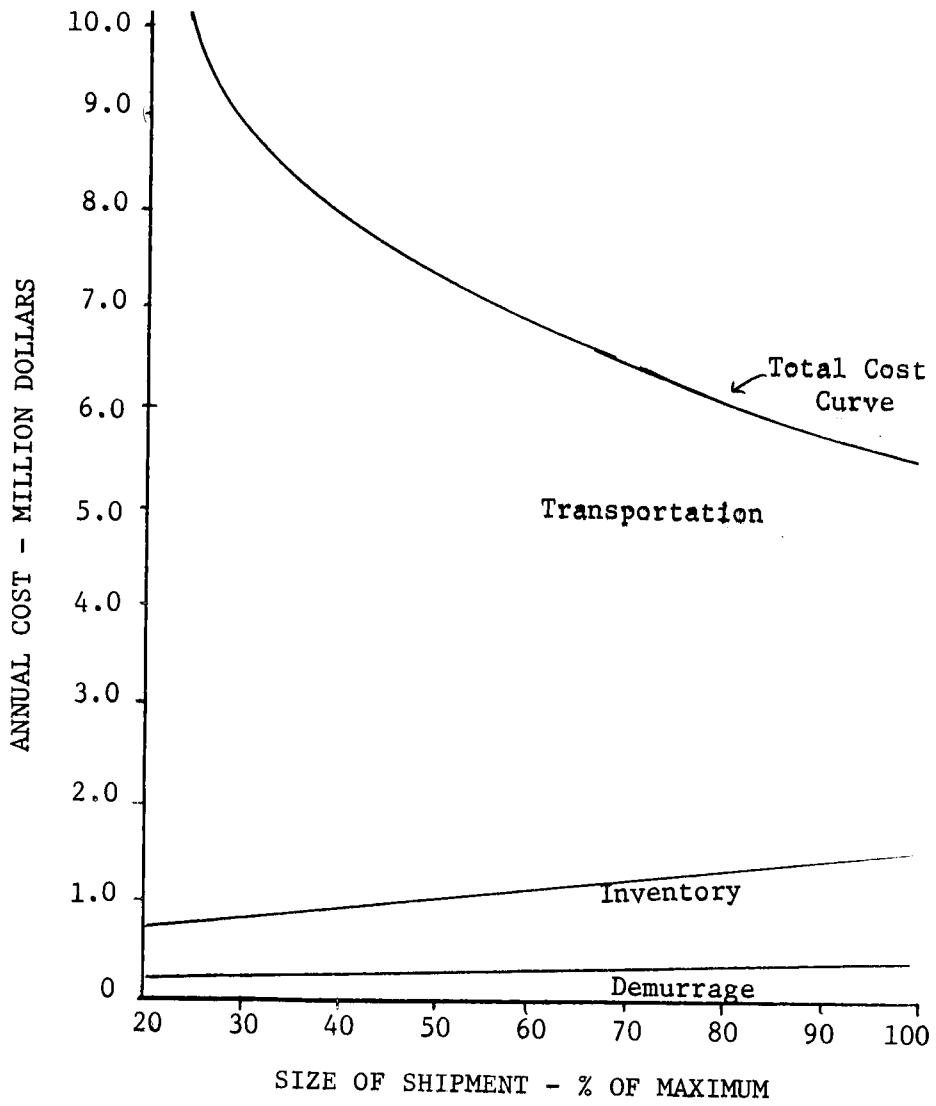


Figure 7. Tradeoff analysis between transportation, inventory and demurrage costs.

TABLE 7

PARAMETER SENSITIVITY ANALYSIS USING DECISION MATRIX

Decision \ Event	Supply from S1 and S2		Supply from S1 and S3		Supply from S1, S2 and S3		Outcome Factor
	Demand Option A	Demand Option B	Demand Option A	Demand Option B	Demand Option A	Demand Option B	
Install Tank	9	8	10	9	7	6	S
	9	8	10	9	7	6	D
	9	8	10	9	8	7	M
Do Not Install Tank	8	6	9	7	6	4	S
	7	6	8	7	5	4	D
	7	6	8	7	5	4	M

Outcome Legend: S = Stock Out Vulnerability

D = Demurrage Costs

M = Mixed Alumina in Tanks

Each outcome factor is ranked between 0 and 10 with 10 being optimum.

time share computer using Basic Language.

A data file called "INVT" was used to input the number of ships to be received during the simulation period, number of days between arrival of each ship, load size in tons for each ship, unloading rate of each ship and the supply plant furnishing each ship load. A copy of this data file is shown in the Appendix, p. 71.

The file "INVT" can be computer generated by use of a program called "ORE 1", Appendix, p. 72. By inputting historical or anticipated probability distributions of ship load size and arrival frequency, "ORE 1" will generate a data file of random arrival frequencies, tonnage, unloading rate and alumina source. The file "INVT" can also be manually generated by taking actual history or a future projection based on a schedule or objective analysis of the criteria involved.

In addition to the input file "INVT", other data is input directly to the main simulation program called "TI" as shown in the Appendix, p. 73. Data input at this point includes a number of dockside tanks, inventory and source type of alumina in each dockside tank, and inventory, consumption, inventory maximum and safety stock at each of the three plants receiving transshipments from the dockside tanks.

Other criteria which are considered in the simulation program "TI" are listed below:

1. An alumina priority system by plant is established which identifies the source of alumina preference to be transshipped from the dockside tanks. In the event that a plant's first choice of product is not available, the second choice is shipped, of if necessary the third choice. The three by

three matrix showing priorities by user plant and supply plant is built into the program.

2. Either the requirement that each source of alumina must be kept segregated in the dockside tanks, or the premise that types can be mixed can be evaluated to determine the effects on storage capacity.
3. The number of supply plants furnishing alumina to the receiving port can be varied from one to four.
4. Rates of transshipment by rail from the dockside tanks to plants D1, D2 and D3 are varied at 0, 1 or 2 times the loading equipment capacity depending on the inventory level at each plant.
5. Dockside tank inventories are adjusted daily for any shipments received or transshipped. Inventories at each of the three plants are adjusted daily for shipments received and consumption.

Simulation Output

Examples of both the summary and daily simulation output are shown in the Appendix, page 74. While the daily output offers a means of monitoring and analyzing the day to day inventory fluctuations and activities of the simulated system, the summary output which depicts the leveled effects on inventories and demurrage costs over a number of days is much more meaningful. Based on the ship arrivals, load sizes and other input data for the simulation period, the following output data was available for analysis:

1. number of times each plant had a stock out;
2. number of times alumina from different sources had to be mixed in the dockside tanks;
3. amount of ship demurrage that had to be paid during the period due to delays in unloading; and
4. amount of the total ship demurrage that was due to a second ship waiting and therefore was not attributed to lack of storage capacity.

Conditions and Results of Simulation Study

Four sets of potential conditions as identified in the decision matrix analysis were simulated. These conditions are described below:

1. Condition A - A new 18,000 metric ton dockside tank was installed and alumina was received at port R1 by ship from all three foreign refining plants. Historical distributions for days between ship arrivals, load size and unloading rates were used.
2. Condition B - Same as Condition A except no tank was installed.
3. Condition C - A new 18,000 metric ton dockside tank was installed. The ship arrival pattern was more consistent as a result of receiving alumina from only S1 and S3 and improvements in the scheduling procedures. The basis for this projected change in the ship arrival pattern is explained in Chapter IV.
4. Condition D - Same as Condition C except no tank was installed.

Two separate simulation runs with twenty-five ship arrivals each were made for each condition. This meant each run simulated a period of approximately 400 days. Starting inventory levels were selected at random from a historical population. The average results from the two runs under each of the four conditions are shown on Table 8.

Decision Tree Analysis

The various combinations of events to be considered had been identified with the decision matrix, and the cost effects on the subsystem comprised of R1, D1, D2 and D3 of each viable alternative were then calculated using the simulation model. Next, since supply sources were the chief criteria in determining whether the $1,000,000 expenditure for more storage capacity at R1 was needed, it was necessary to determine the economic impact of changing the supply-demand distribution on the total alumina system. Since other macro considerations, such as moving a project with specific demand constraints from D7 to D8, were under investigation, the decision tree analysis shown on Figure 8 was used to evaluate the system economics of each choice.

A net present value comparison for each alternative branch of the tree is shown on the chart. This comparison showed that the most economical combination of alternatives, as shown by the heavily marked path, was to restrict the supply for R1 to two sources and not install the new storage tank. The net present value calculations were based on discounted cash flow analysis using a 10 percent cost of capital, a 48 percent tax rate, fourteen year depreciation life, and sum-of-years' digits depreciation method.

TABLE 8

SUMMARY OF SIMULATION RESULTS

	Supply Source			
	S1, S2 and S3		S1 and S3	
Condition	A	B	C	D
Number of Dockside Tanks	5	4	5	4
Number Ships Simulated	50	50	50	50
Number Days Simulated	800	800	800	800
Annual Demurage Cost	$25,000	$143,000	0	$66,000
Number of Stock Outs	0	0	0	0
Number Times Alumina Mixed	3	19	1	4

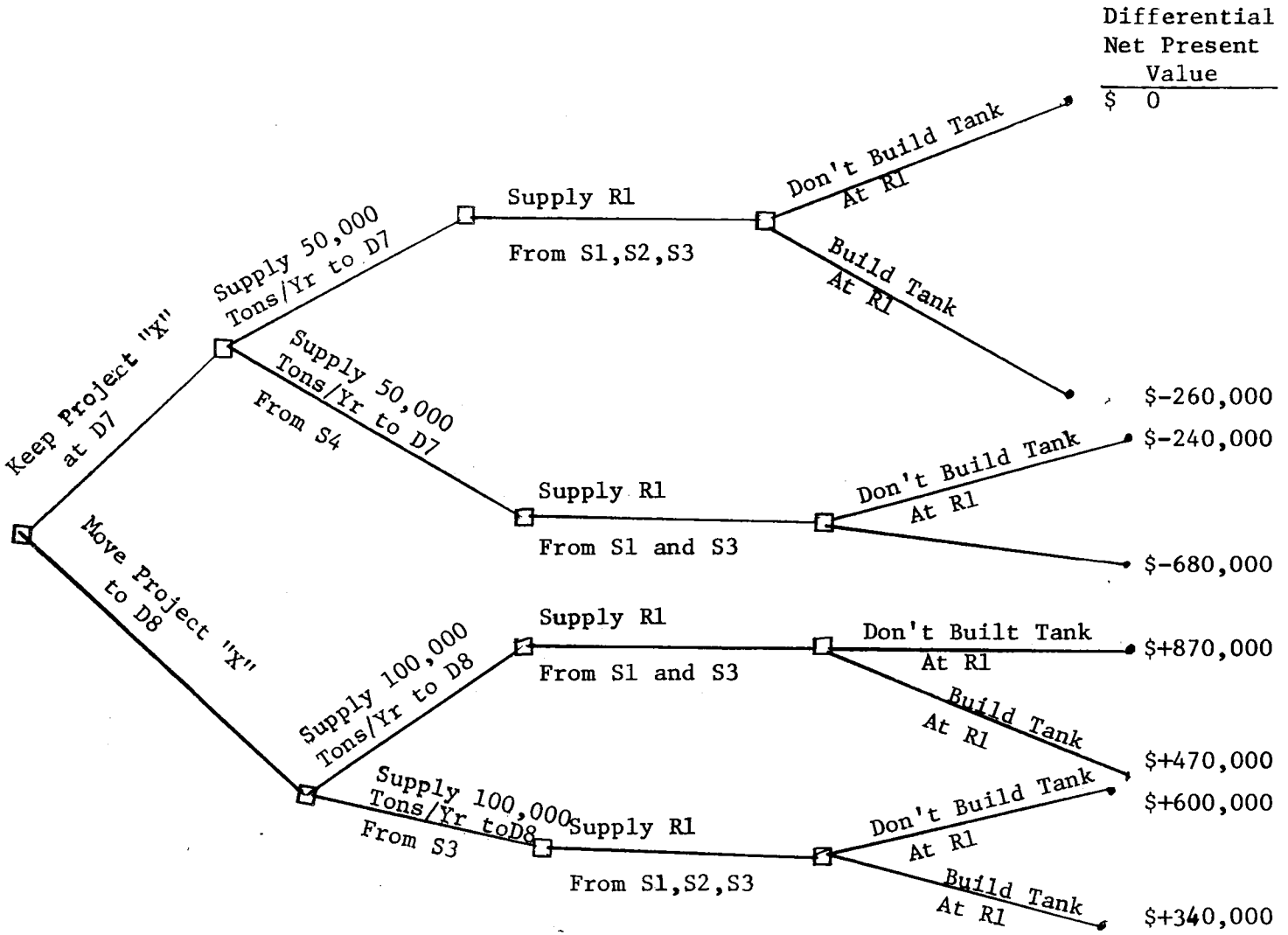


Figure 8. Decision tree analysis of alumina system alternatives.

CHAPTER IV

DEVELOPMENT OF SCHEDULING MODEL

Major Scheduling Considerations

After considerable evaluation of the alumina scheduling procedures and parameters, it became apparent attention should be focused on the two pertinent characteristics of the system listed below:

1. There are three time horizons which must be dealt with in scheduling alumina. These will be referred to as the long, intermediate and short time horizons.
2. Transportation and stock out costs are overpowering when considering tradeoffs with inventory holding and demurrage costs. The challenge is therefore one of regulating flows and inventories within guidelines established to minimize transportation costs.

Long Time Horizon

Schedules for movement of alumina must be projected ahead for four months or more to plan and allocate the various facilities and resources needed, and to coordinate this movement with plant operating levels and other interrelated systems. Tentative arrangements must be made for chartering ships, barges and large rail shipments. Inventory control is a prime consideration in this time frame only to the extent that changes in refining or smelting plant operating or alumina sales levels are anticipated.

The greatest concern looking this far in advance is establishing

a distribution pattern that minimizes transportation costs within accepted demand parameters. A permanently feasible plan is developed to satisfy this proviso over the next planning period with little regard for the stochastic elements of the system. The optimum routing as determined by the currently used computerized transportation algorithm is updated at approximately six month intervals.

Intermediate Time Horizon

One to two months prior to shipments leaving the origin is a critical time in the scheduling procedure. The greatest control over the inventory levels and arrival distributions can be exercised during this period just prior to scheduled dates for specific ships, barges and large rail shipments being firmly committed. This is the last opportunity to fine-tune the large movements of alumina to compensate for any new knowledge that has been gained about the system since establishing the long time horizon schedule.

Short Time Horizon

During the periods shipments are enroute and even several weeks prior to scheduled departure from the origin, considerable new knowledge about the stochastic elements of the system are available; however, the ability to make compensating changes to the schedule are limited. Scheduling changes are limited to such actions as adding rail car lots or possibly diverting a shipload from one port to another.

Multi-Stage Linear Programming Model

A multi-stage computer algorithm with general linear structure

was developed to span the three time horizons. A description of the pertinent characteristics of the program is listed below:

1. Twelve weekly stages were set up with the anticipated consumption for each smelting plant and the supply from each refining plant to be input for each of these weeks.
2. Transportation rates in dollars per ton and average travel time for available types of carriers and discrete quantity shipment levels were input for each potential route.
3. Current, maximum and minimum inventory tonnage levels were input.
4. Shipments enroute were input by crediting them to the demand plants' inventory when shipped.
5. A shipping schedule to provide minimum transportation costs for the ensuing twelve weeks was updated each week based on projected supply-consumption quantities, updated inventories and the stipulated maximum and minimum inventory limits.
6. The program, which was run on an IBM 360 computer, had 253 rows, 714 variables and 1421 elements. The Mathematical Programming System (MPS/360) which was designed by IBM was used.

Upon examination of the schedule generated by this program, it became obvious the results were not optimal. The fallacies were attributed to the linearity and combinational assumptions, the failure to properly recognize the discrete shipment quantities, and also the failure to recognize that schedules can not realistically be changed after commitments have been made for carriers. At this point a reassessment

of the system dampened the incentive to use a multi-stage model and the program was abandoned. The logic in arriving at this decision is listed below:

1. A mixed integer program was needed to properly portray the fixed quantity shipments for a multi-stage model.
2. The fact that emphasis is given to different control variables in the long and short time horizons suggested that bridging these horizons into one led to suboptimization. No real regard for inventory variations, discrete shipment quantities and carrier arrival pattern distributions are necessary long range while these are of prime concern in the short run.
3. It was feared the program logic would result in transportation costs being suboptimized to satisfy a short time horizon constraint.
4. The generalized transportation program currently being used for calculating the minimum cost supply-demand matrix seemed quite adequate for providing long term optimum routing. It was found that while some short horizon deviations from this routing had been necessary in the past due to the stochastic elements of the system, part of these deviations could be avoided in the future by fine-tuning scheduling procedures at the intermediate time horizon.
5. The complexity and uncertain results associated with the multi-stage model made this package extremely difficult to sell to those that would be responsible for using it.

Non-Linear Approach

Efforts were then turned to developing a computerized non-linear scheduling and inventory control algorithm for the intermediate and short time horizons. The logic for the program was based on controlling inventories so the optimum routings as determined by the transportation algorithm could be followed. The following parameters were built into the logic:

1. Make a shipment over an optimum route between a supply plant SX, and a demand plant, DX, any time the inventory at SX and the available capacity at DX were sufficient to ship the most economical shipment quantity.
2. Ship quantities from SX to the demand plant, DY, yielding the next lowest transportation cost only if SX inventories are at maximum capacity and DX does not have adequate capacity to take the discrete quantity to be shipped, or DY is at the minimum inventory level and the optimum supplier, SY, does not have an adequate inventory to send the most economical shipment quantity to DY.

The logic chart for a refining plant and its potential customers is shown in Figure 9. While this approach gave near optimal results it was plagued with a possible sub-optimal assumption concerning the discrete shipment quantities. It assumed in those cases when the optimum routing could not be used with the most economical discrete shipment quantity it was better to use the second most optimal route than to reduce the shipment size. It was then determined that this potential

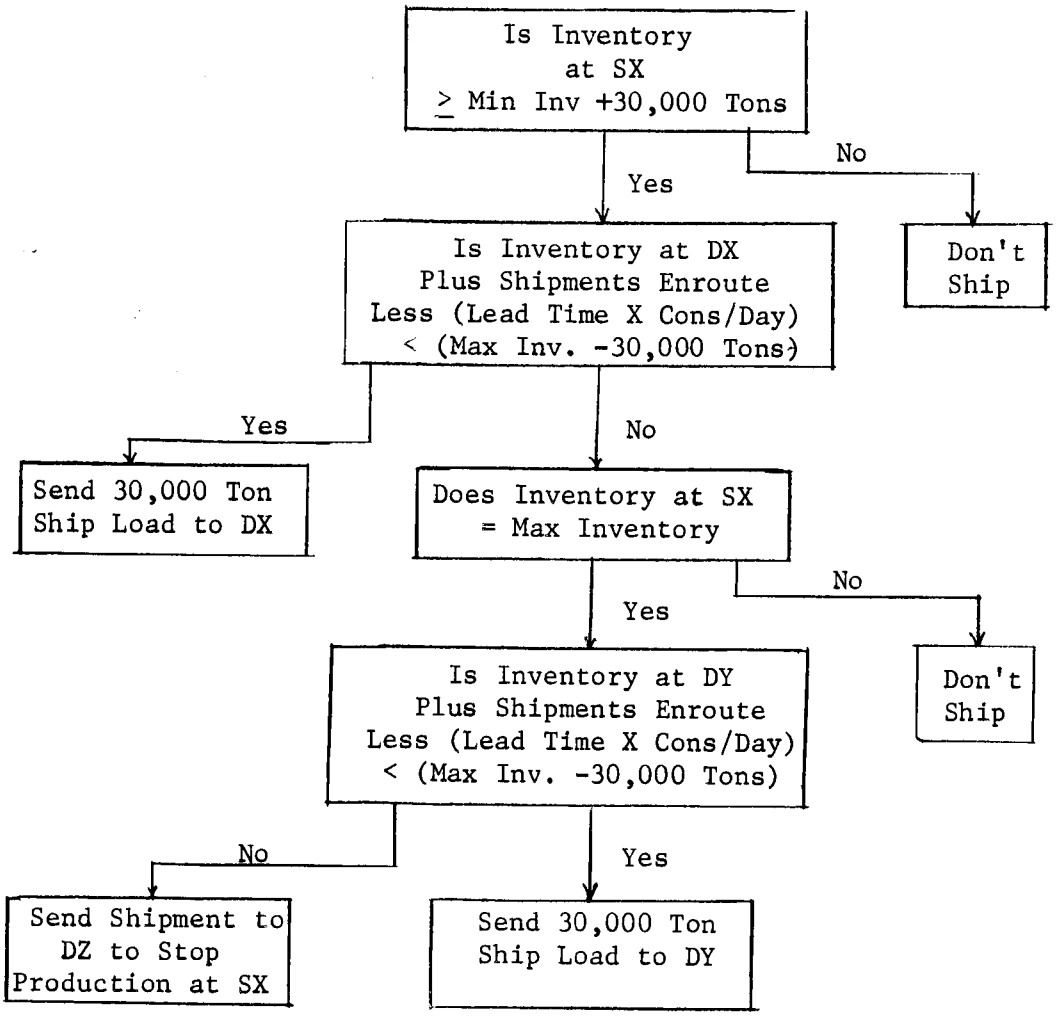


Figure 9. Inventory control and scheduling algorithm.

shortcoming could be overcome by determining the breakeven point between selecting another route and reducing the shipment size for each case and then adding branches to the logic flow chart.

Appraisal of Ship Scheduling Emphasis and Criteria

It became apparent that where the major emphasis in scheduling ships had been in inventory control, there was growing need to give more attention to ship arrival patterns at both pickup and delivery points. This meant a change in replenishment policy which would give more emphasis to fixed interval scheduling and less emphasis to periodic reorder scheduling was needed. The need was particularly pronounced at R1 where number of supply sources was increasing, demand was increasing, and effective storage capacity was being decreased.

The remainder of this chapter is devoted to developing the logic for more precise scheduling in the short and intermediate time horizons. Criteria or considerations which were determined to offer the greatest potential for improvement were a conditioned version of fixed interval scheduling, more finite consideration of travel time and the method of expressing schedule dates to the shipper.

Improved Travel Time Estimates

The statistical analysis of ship travel times on Table 3 of page 20 provided historical mean travel times for each route. These means of 28 days for route S1-R1, 19 days for S2-R1 and 15 days for S3-R1 should be used in long time horizon scheduling.

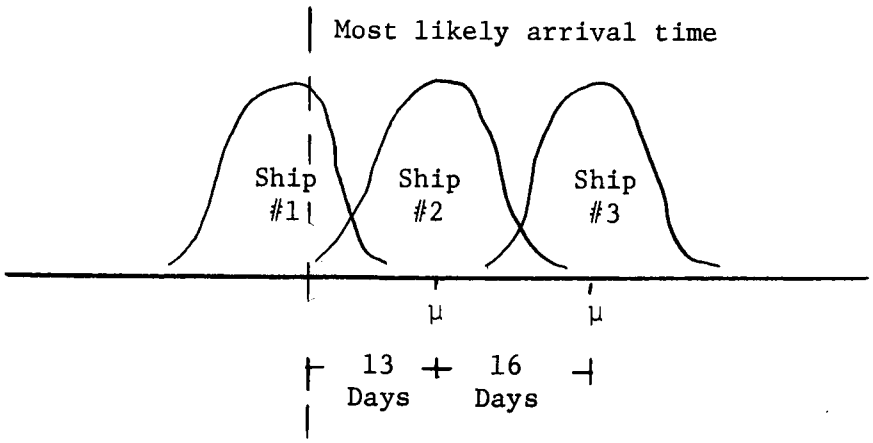
The analysis showed that travel time variations up to three days

can be attributed to the differences in speed of various ships. The statistical analysis indicated the elimination of ship speed as one of the stochastic elements causing travel time fluctuations would reduce the $\pm 2\sigma$ travel time variation from eight days to six days. Figure 10 shows the effect on a group of successive ship arrival distributions of altering the schedule based on the conditional probabilities after allowing for the rated speed of a specific ship. Figure 10(B) shows the mean arrival time can be rescheduled on each ship if the opportunity exists to compensate for a ship's rated speed in its schedule. It is also noted that the arrival time variation is improved over Figure 10(A) for each ship as a result of using the conditioned probability.

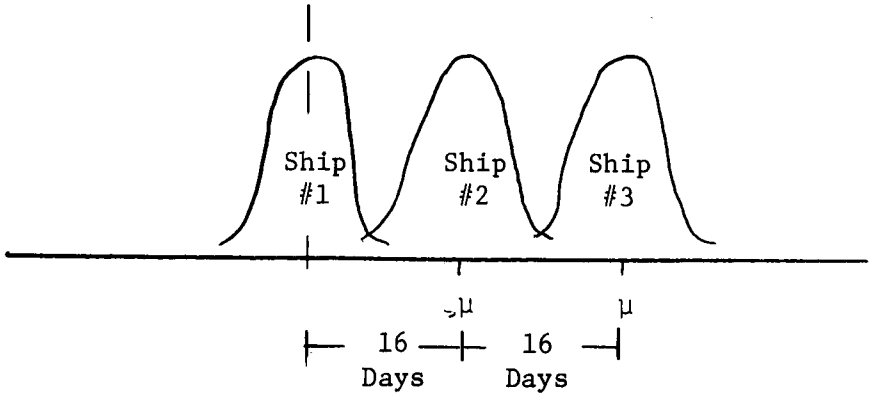
Figure 10(C) shows that if it proves not practical to alter the schedule of a ship, then the arrival interval can still be improved by altering the schedule of succeeding ships. Maximum benefit to the scheduling process from this knowledge occurs if the schedule adjustment can be made at the time a ship is chartered. Under the present scheduling procedures the information concerning a ship's speed is not available until after the ship's departure time from the refinery and arrival time at the receiving port have been scheduled. However, this may be possible in the future by one of the two following methods:

1. The vessel's rated speed can be taken into account at the time of negotiation for a contract by the customer specifying a schedule to coincide with the speed of the ship under consideration.
2. In the process of chartering a ship the customer could specify

(A) Without Conditional Probability Allowance



(B) With Conditional Probability Allowance for Speed as Ship is Scheduled



(C) With Conditional Probability Allowance for Speed Made on Succeeding Ships After Ship is Scheduled

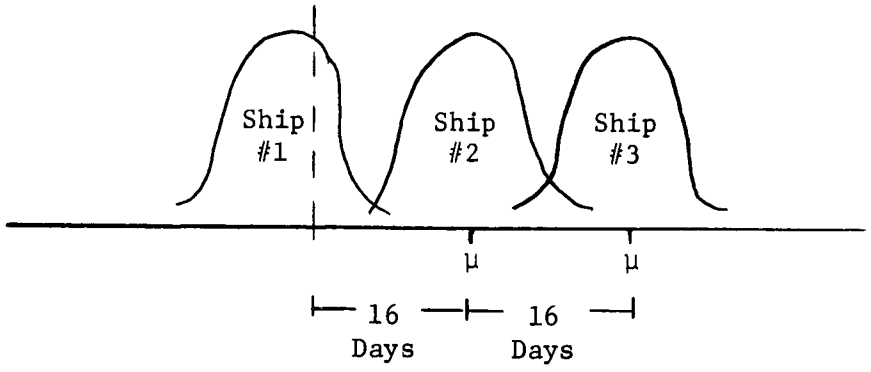


Figure 10. Effect of conditional probability on ship arrival pattern.

only an arrival time at the destination and the shipper would then take into account the ship's rated speed in scheduling the departure time from the origin.

Single Point Versus "Lay Days" Scheduling

An analysis of present scheduling procedures showed that for 75 percent of the ships, the time schedule given to the shipping company for departure from supply plants were expressed as a "lay day" range and for the other 25 percent of the ships, a single point date was given. In the case of arrival schedules for the demand plants, a "lay day" range was given for 20 percent of the ships and a fixed point for the other 80 percent.

A statistical analysis of the departure and arrival dates under various combinations of each scheduling method was made to determine which gave the best results. Results of this analysis are shown on Table 9. A computerized multiple regression analysis was also made to test for a correlation between the methods used and results. The computer output from this investigation is shown in the Appendix, page 75. In both cases no consistent correlations could be found between methods and results. The lack of identifiable correlation was attributed at least in part to the small number of samples available for each scheduling method. Despite the lack of supporting correlation data, the following conclusions concerning the use of single point versus "lay day" scheduling were intuitively made:

1. The use of "lay day" scheduling tends to obscure the desired date for departures or arrivals in a range and therefore

TABLE 9

ANALYSIS OF SCHEDULING RESULTS USING SINGLE POINT AND "LAY DAY" RANGE METHODS

Scheduling Method Used For Departure Date For Arrival Date	Single Point Single Point	Lay Day Range Single Point	Lay Day Range Lay Day Range	Total
Number of Voyages Sampled	5	12	3	20
Actual Versus Scheduled Departures				
Range in Number of Days	0 to +9	-7 to +17	-10 to +17	-10 to +17
Mean Variation from Schedule	+3.3 Days	+2.8 Days	+3.7 Days	+3.0 Days
Number Ships Late	3	7	2	12
Number Ships Early	1	2	1	4
Number Ships on Time	1	3	0	4
Actual Versus Scheduled Arrivals				
Range in Number of Days	-3 to +7	-7 to +15	-11 to +10	-11 to +15
Mean Variation from Schedule	+0.8 Days	+3.0 Days	+2.0 Days	+2.3 Days
Number Ships Late	2	9	2	13
Number Ships Early	2	1	1	4
Number Ships on Time	1	2	0	3

contributes to conflicting interpretations. Based on inventory levels or other influencing pressures, the scheduler sometimes places the desired date at the front or end of the given range instead of the mean. This inconsistency causes the ship arrival patterns to be more erratic.

2. Minimum variation from a desired schedule will occur if a single point estimate is used by the customer for expressing a desired schedule. Any discretionary control over the schedule that the ship captain or owner is capable of exercising can then be pointed toward a specific date rather than an ambiguous range.
3. To satisfy the "lay day" requirement a tolerance of ± 5 days can be assigned around the specific date requested.
4. Theoretically, the most consistent ship arrival time pattern at port R1 can be achieved if the customer furnishes only the requested arrival date at R1 with a tolerance. Any discretionary control over the schedule the ship captain or owner has on previous voyages or the voyage being chartered concerning ship speed, route to travel or when the ship makes extra stops for crew leaves or maintenance can be pointed toward the requested arrival date. The shipping company could then assign a "lay day" range for scheduled departure from the origin and report this schedule to the customer.

Ship Tardiness

As indicated by Table 4 on page 23 the average ship leaves the

origin 3.0 days later than scheduled and arrives at the destination 2.3 days later than scheduled. This chronic tardiness for 60 percent of the ships is an indication that the contingencies or fat built into the ship's schedules to cover the uncertainties of the sea are not adequate for the average ship. This tardiness was accepted as a realistic constraint in attempts to improve the scheduling and inventory control procedures. In analyzing and revising the scheduling process, this tardiness was recognized as a stochastic element which widens the voyage time distribution and causes it to be skewed to the right.

Inventory Control Model

At this point it is recognized that a delicate balance between inventory control and a consistent ship arrival pattern is needed at port R1 if the installing of more capacity, demurrage costs and mixing of alumina are to be avoided. To accomplish this balance a modified fixed interval model was developed. In addition to the modifications to the fixed interval schedule for ship speeds, subtle schedule changes need to also be made in the intermediate time horizon to maintain inventories at desired levels. Several methods for monitoring and controlled smoothing of inventories including the use of an inventory running average or exponential smoothing equation were considered before deciding on an inventory control algorithm. The algorithm is designed to calculate an inventory response factor (k) which can then be used to subtly modify the fixed interval schedule. The formula for calculating the inventory response factor is:

$$k = \frac{I + T}{S + A + [C(N+L)]}$$

Where: I = combined inventory in metric tons at R1, D1, D2 and D3

k = inventory response factor

T = transient inventory in metric tons

S = safety stock in metric tons

A = desired anticipation stock in metric tons

C = total consumption of plants D1, D2 and D3 in metric tons per day

N = number of days until scheduled arrival of any transient inventory

L = average number of days a ship is tardy

Pertinent comments concerning the use of this formula are listed below:

1. Because of the long travel time and large quantities being shipped, the transient inventories are a key consideration for inventory control at R1, D1, D2 and D3.
2. The desired level of anticipation stock will be revised periodically to compensate for production smoothing, changes in operating levels or alumina sales.
3. As an inventory cushion against the tradiness of a ship, tardiness value (L) of three days should normally be used.

The inventory response factor (k) should be calculated each month after the physical inventories have been reported from each plant. Then based on the "k" value the appropriate modifications to the schedule of all unnamed ships can be made. The responses to different values of "k" which should be initially used are shown in Table 10.

TABLE 10

SCHEDULE RESPONSE TO INVENTORY LEVEL

"k" Value	Schedule Change to be Made in Interval Between Arrivals
Below 0.76	Need Quick Shipment
0.76 to 0.85	- 2 Days
0.86 to 0.95	- 1 Days
0.96 to 1.05	No Change
1.06 to 1.15	+ 1 Day
1.16 to 1.25	+ 2 Days
1.26 to 1.35	+ 3 Days
1.36 to 1.45	+ 4 Days
Above 1.45	Suspend Shipments

The response parameters should be reviewed and revised as necessary after they are put into use. It should be noted from the chart that it may be necessary to override the subtle correction of inventories using the "k" value if the extremes of safety stock or maximum storage are approached as a result of inventories getting out of control.

Effects of Supply Sources on Schedule

Shipments to receiving port R1 had been supplied primarily by refining plants S1 and S2 in the past. With the recent startup of the third foreign refining plant, S3, the possible combinations of supply to

R1 were S1 and S3, S1 and S2, or S1, S2 and S3. The decision tree analysis in Chapter III clearly showed that the supply sources to R1 should be limited to S1 and S3 if excessive demurrage costs or the installation of additional storage capacity could be avoided. Although the historical information concerning the shipping patterns from the new plant S3 to R1 was limited, the analysis of available information left little doubt that the closest control over shipping schedules and inventories could be maintained with S1 and S3 being the suppliers. Reasons for expecting a more consistent ship arrival pattern at R1 with S3 as the second supplier instead of S2 are listed below:

1. The mean travel time from S3 to R1 was 15.0 days compared to 19.3 days from S2 to R1. There would be an average of 1.25 ships enroute at all times and 452 travel days per year if S1 and S3 are supplying R1. This compares to 1.40 ships enroute and 500 travel days per year if S1 and S2 are supplying R1. Average transient inventories are almost 5,000 tons higher with S2 versus S3 being a supply source to R1.
2. Arrivals and departures at S2 vary more than for S3 because of delays associated with the ocean tides.
3. Limited storage capacity at S3 and economical ship load size dictates that ships load and depart on a relatively regular schedule. The frequency range between departures must be constrained between 20 and 32 days.
4. All of the capacity from refining plant S3 would be dedicated to R1 thus assuring a captive and steady source.

Each of these reasons contribute to a more predictable ship arrival pattern at R1 and consequently less demurrage costs and better inventory control. Based on a conservatively calculated improvement in the R1 arrival distribution resulting from these reasons, the expected benefits from changing suppliers is seen by comparing Conditions B and D of the simulation study results from Table 8 on page 41.

Fixed Interval Model

The parameters which seemed to have a significant bearing on developing a fixed interval model for scheduling shipments from S1 and S3 to R1 were analyzed and are discussed below.

1. According to the Corporate Plan, shipments are to be made at the average rate of one ship load every 45 days from S1 and a load every 24 days from S3.
2. Based on production rates, commitments to other customers and storage capacity at the refining plants, it was determined that the practical frequency variation between departures is 12 to 70 days for S1 and 20 to 32 days for S3. Assuming average sized ship loads, the departure frequency intervals should not be planned outside of these ranges.
3. An average sized ship load is needed at R1 every 16 days. The minimum time to be scheduled between ships to allow enough time for unloading and schedule variations and hence avoid having two ships in port simultaneously is 10 days. Storage capacity available at R1 may dictate a higher minimum at times. The maximum time allowable between ship depends on inventory

levels; however, it should normally not exceed 30 days unless it is necessary to suddenly change the anticipation inventory goal.

4. Mean travel time is 28 days from S1 and 15 days from S3. To minimize the probability of two ships in R1 at once a S3 ship can not depart during the period from 3 days after to 23 days after a ship departs from S1.

Using these parameters a number of potential fixed interval models were developed and evaluated. The evaluation of each consisted of manually simulating the system with at least ten ships to determine the effects on inventories and schedules. The evaluation of the model selected as one giving the best balanced system is shown on Table 11. In this particular simulation the inventory response factor (k) was 1.0 based on the R1 system beginning inventory of 80,000 tons, therefore it was not necessary to adjust the normal ship arrival frequency rate of 16 days.

TABLE 11

EVALUATION OF FIXED INTERVAL MODEL

Ship No.	Origin	Load Size Metric Tons	R1 Arrival Days Since Last	R1 Arrival Days Calendar	R1 Combined R1,D1,D2 & D3 Inventory Metric Tons	S1 Departure Days Since Last	S1 Departure Days Calendar	S1 Inventory Metric Tons	S3 Departure Days Since Last	S3 Departure Days Calendar	S3 Inventory Metric Tons
				0	80,000					0	4,000
1	S1	35,000	14	28	87,000		0	37,000			
2	S3	30,000	14	42	89,000				28	28	9,000
3	S3	30,000	20	62	79,000				20	48	4,000
4	S1	35,000	14	76	86,000	48	48	43,000			
5	S3	30,000	14	90	88,000				28	76	9,000
6	S3	30,000	20	110	78,000				20	96	4,000
7	S1	35,000	14	124	85,000	48	96	30,000			
8	S3	30,000	14	138	87,000				28	124	9,000
9	S3	30,000	20	158	77,000				20	144	4,000
10	S1	35,000	14	172	84,000	48	144	28,000			

CHAPTER V

REFLECTIONS AND RESULTS

Characteristics of the System

The importance of a thorough understanding of the system, its pertinent variables, and how it interacts with the world around it has been indelibly imprinted on the author's mind as a result of this optimization study. Since this system was unique in many respects, it seems only appropriate to reiterate its more pertinent characteristics.

1. Transportation and stock out costs were overpowering. Large shipment quantities were relatively fixed to achieve minimum transportation cost.
2. The distribution of alumina by ocean freighter was the most dynamic part of the system. Considerable variability in travel time and load size and consequently inventory existed.
3. Ship arrival patterns were erratic at times. In one case three ships arrived at port R1 in a period of seven days. The need for a most consistent arrival frequency was apparent.
4. Large safety stocks and transient inventories were held to guard against stock outs and because of the long travel time and large quantities being shipped.
5. There were a number of demand constraints to be reckoned with.
6. Long range scheduling was necessary to charter the carriers needed.
7. Ship demurrage costs of over $3,000 per day were a significant

consideration from the standpoint of unloading rate while in port and avoiding more than one ship in port at a time.

Evaluation of Techniques and Methods Used in Study

In addition to the shear brute force and accompanying shotgun volleys, a number of worthwhile methodologies were employed. A brief evaluation of the techniques used is made below:

1. Statistics and probability theory were very useful in evaluating the various populations. Specific applications included the use of the mean, standard deviation, range, normal distribution, conditional probability, Markov chains, and correlation analysis.
2. Simulation proved to be an effective numerical method of evaluating the system under different conditions. The application of simulation to this type problem having historical distribution data on a number of variables seems appropo.
3. The power of the computer which was used with the simulation study, regression analysis and transportation algorithm must not be overlooked as an expedient supplement to the analytical and scheduling endeavors.
4. Linear programming was used in the form of both a general transportation problem algorithm and also a multi-stage scheduling algorithm. The transportation algorithm has proven to be uncomplicated and effective. The multi-stage scheduling algorithm was unsatisfactory because in addition to other limitations it did not have integer capabilities. A

new MPSX/360 system with mixed integer capabilities has just recently become available, and its use should be considered for this application.

5. The logic for a non-linear computer program was developed to try and circumvent some of the faulty linearity and combinational assumptions that were inherent in the multi-stage algorithm. This approach proved to be quite successful.
6. Inventory theory involving the consideration of replenishment methods such as fixed orders and periodic reordering, safety stocks, anticipatory stocks, movement stocks, lot size stocks and inventory balancing was used extensively in developing and testing various control systems.
7. Scheduling theory as it related to inventory control, and fixed point estimates versus interval scheduling proved to be beneficial in developing and evaluating schedule effectiveness.
8. The principles of economic evaluation embracing the time value of money, cash flows, present worth, capital recovery, depreciation and tax implications were used extensively in the study to calculate the optimum economical balance of resources.
9. Other scientific management tools such as decision trees and decision matrices were very helpful in identifying and evaluating various combinations of alternatives.

Results and Proposals from the Study

A summary of the results and proposals from the study are listed below:

1. Smelting plants D1, D2 and D3 should be supplied from refining plants S1 and S3. Based on this supply pattern and recommended improvements in scheduling procedures there should be more consistent ship arrival patterns and inventories at R1. Based on these projected improvements, a decision on the previously proposed new storage tank at R1 was postponed for one year. The system will be monitored during this period using the simulation algorithm to evaluate inventories and demurrage costs as they would have occurred with an additional tank versus without an extra tank.
2. The proposed safety stocks will be evaluated over the next three months by monitoring the inventory fluctuations at each plant to determine if any stock out threats occur.
3. A new conveyor is currently being installed at R1 to speed the loading of alumina from the dockside tanks into rail cars for transshipment to D2 and D3, and thereby give more flexibility in inventory balancing.
4. Use of the new modified fixed interval scheduling algorithm for ocean shipments to R1 on a trial basis has been recommended. Any resulting improvement should decrease demurrage costs and give assurance that additional storage capacity is not needed at R1.

A ship schedule and alumina balance status report covering a time horizon of approximately six months, which would be updated each month, has been designed to use with the algorithm. The format for this report

is shown on Table 12. The report will be divided into three sections: the short horizon listing those ships enroute; the intermediate horizon listing those ships that have been named and firmly scheduled; and the long horizon listing those unnamed ships with their tentative schedule by number. The inventory response factor (k) should be calculated monthly so the scheduled arrival frequency of unnamed ships can be adjusted accordingly.

TABLE 12

SHIP SCHEDULE AND ALUMINA BALANCE

_____1, 1973

			R1			S1		S3		
			Arrival			Departure		Departure		
Ship	Origin	Load Size	Date	Days Between	Inventory Metric Tons	Date	Days Between	Date	Days Between	Inventory Metric Tons

$$K = \frac{I + T}{S + A + [C(N+L)} =$$

BIBLIOGRAPHY

BIBLIOGRAPHY

Beggs, Robert I., Herlihy, Robert E., Mall, Robert T., and Springer, Clifford H. Statistical Inference. Homewood, Illinois: Richard D. Irwin, Inc., 1966.

Buffa, Elwood S. Readings in Production and Operations Management. New York: John Wiley and Sons, Inc., 1966.

Conway, Richard W., Maxwell, William L., and Miller, Louis W. Theory of Scheduling. Massachusetts: Addison-Wesley Publishing Company, 1967.

Dantzig, George B. Linear Programming and Extensions. New Jersey: Princeton University Press, 1963.

Gass, Saul I. Linear Programming. Third Edition. New York: McGraw-Hill Book Company, 1969.

Grant, Eugene L. and Ireson, W. Grant. Principles of Engineering Economy. Fourth Edition. New York: The Ronald Press Company, 1960.

Hadley, G. Linear Programming. New York: Addison-Wesley Publishing Company, Inc., 1962.

Hillier, Frederick S. and Lieberman, Gerald J. Introduction to Operations Research. San Francisco: Holden-Day, Inc., 1967.

Llewellyn, Robert W. Linear Programming. New York: Holt, Rinehart and Winston, Inc., 1964.

Sasieni, Maruice, Yaspan, Arthur, and Friedman, Lasrence. Operations Research----Methods and Problems. New York: John Wiley and Sons, Inc., 1959.

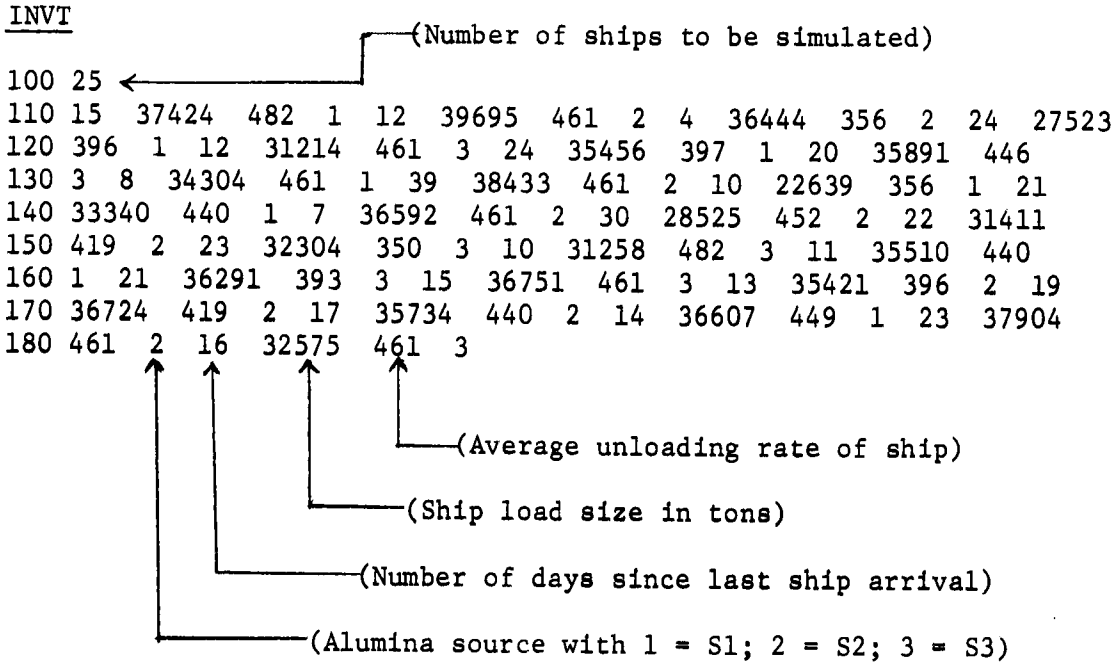
Springer, Clifford H., Herlihy, Robert E., and Beggs, Robert I. Advanced Methods and Models. Illinois: Richard D. Irwin, Inc., 1965.

Springer, Clifford H., Herlihy, Robert E., Mall, Robert T., and Beggs, Robert I. Probablistic Models. Illinois: Richard D. Irwin, Inc., 1968.

APPENDIX

APPENDIX

SIMULATION DATA FILE "INVT"



SIMULATION DATA FILE "ORE 1"

```
ØRE1

HØW MANY SHIPS DØ YØU WANT TO SIMULATS??25
YØUR DISTRIBUTIØNS WILL BE IN THE FØLLØWING ØRDER
#1 IS FØR ARRIVALS...#2 IS FØR SHIP SIZES
THIS IS THE # 1 DISTRIBUTIØN
WHAT IS THE LØWER BØUND VALUE AND HØW MANY DIVISIØNS ARE IN
YØUR HISTØGRAM??0,8
LIST THE UPPER BØUND ØF EACH DIVISIØN AND THE FREQUENCY ØF
THAT DIVISIØN  (I.E.  18000,7)
?5,2
?10,7
?15,6
?20,4
?25,3
?30,1
?35,1
?40,1
THIS IS THE # 2 DISTRIBUTIØN
WHAT IS THE LØWER BØUND VALUE AND HØW MANY DIVISIØNS ARE IN
YØUR HISTØGRAM??15000,9
LIST THE UPPER BØUND ØF EACH DIVISIØN AND THE FREQUENCY ØF
THAT DIVISIØN  (I.E.  18000,7)
?18000,1
?21000,1
?24000,2
?27000,3
?30000,4
?33000,5
?36000,6
?39000,2
?42000,1
```

INPUT TO SIMULATION MASTER PROGRAM "TI"

```
CLE
READY
RUN TI

TI     12:52     07/28/72

HOW MANY TANKS AT  DOCKSIDE FOR THIS SIMULATION?
?4
AMOUNT AND TYPE INTANK 1 =?12000,A
AMOUNT AND TYPE INTANK 2 =?14000,S
AMOUNT AND TYPE INTANK 3 =?10000,A
AMOUNT AND TYPE INTANK 4 =?12000,S

AMOUNT AT PLANT  V-?10000
AMOUNT AT PLANT  W-?10000
AMOUNT AT PLANT  H-?0
AMOUNT AT PLANT  X-?0

THE CONSUMPTION RATE AT  V IS 535 TONS/DAY
THE CONSUMPTION RATE AT  W IS 862 TONS/DAY
THE CONSUMPTION RATE AT  H IS 575 TONS/DAY
THE CONSUMPTION RATE AT  X IS 0 TONS/DAY

WHAT IS THE STORAGE CAPACITY AT  V-?20500
::::INVENTORY PARAMETERS::::

V   MAX--- 20500 TONS     MIN--- 0 TONS
W   MAX--- 31000 TONS     MIN--- 0 TONS
H   MAX--- 17500 TONS     MIN--- 0 TONS
X   MAX--- 17500 TONS     MIN--- 0 TONS

DO YOU WISH DAILY OR SUMMARY SIMULATION OUTPUT?
TYPE 1 FOR DAILY OR 2 FOR SUMMARY,WHICH  ?1
```

SIMULATION STUDY OUTPUT

```
DAY 17
SHIP = 0        A
TANK 1 = 5356.5                 S
TANK 2 = 0      Z
TANK 3 = 18000 A
TANK 4 = 13357.5                A
TANK 5 = 0      Z
LOCATION V= 14547.5
LOCATION W= 17327
LOCATION H= 4887.5
LOCATION X= 0

DAY 18
SHIP = 0        A
TANK 1 = 3201   S
TANK 2 = 0      Z
TANK 3 = 18000 A
TANK 4 = 12555 A
TANK 5 = 0
LOCATION V= 14815
LOCATION W= 17758
LOCATION H= 5175
LOCATION X= 0

THE NUMBER OF DAYS SIMULATED WAS 18
THE NUMBER OF SHIPS ARRIVING WAS  2
V  WAS OUT OF ORE 0 TIMES
W  WAS OUT OF ORE 0 TIMES
H  WAS OUT OF ORE 0 TIMES
X  WAS OUT OF ORE 0 TIMES
ORE WAS MIXED 0 TIMES
THE AMOUNT OF DEMURRAGE WAS APPROXIMATELY  $ 4020.03
OF THIS TOTAL  $ 0 IS DUE TO SECOND SHIP WAITING
FINAL INVENTORIES
TANK 1 = 3201   S
TANK 2 = 0      Z
TANK 3 = 18000 A
TANK 4 = 12555 A
TANK 5 = 0      Z
LOCATION  V= 14815
LOCATION  W= 17758
LOCATION  H= 5175
LOCATION  X= 0
```

CORRELATION ANALYSIS SCHEDULING METHODS AND RESULTS

```
STEP-WISE MULTIPLE REGRESSION

        1.4903 SY     19.  DF

WHAT NEXT, SL ØR F?  SL

GIVE THE SIGNIFICANCE LEVEL  .05

      0.0040 CRITICAL F    0.050 SIGNIFICANCE LEVEL

STEP  1       ENTER X 2
      0.0156 F
      0.0156 F R-SQ
      1.5305 SE      18.  DF
      0.0009 R-SQ
      1.0000 DET
                        T Test      I-R          CØEF    SE ØF CØEF
Y 1  =     3.3689                                3.3689E.00
          -0.0034 X 2 -0.125    0.000  -3.3939E-03    2.7131E-02

WHAT NEXT?  M

ENTER Y SUBSCRIPT, THEN ALL X"S
:2,1

      12.9416 SY    19.  DF

WHAT NEXT, SL ØR F? SL

GIVE THE SIGNIFICANCE LEVEL  .05

     0.0040 CRITICAL F     0.050 SIGNIFICANCE LEVEL

STEP 1       ENTER X 1
     0.0156 F
     0.0156 F R-SQ
    13.2904 SE      18.  DF
     0.0009 R-SQ
     1.0000 DET
                       T TEST       I-R          CØEF    SE ØF CØEF
Y 2 =   21.1445                                2.1145E+01
        -0.2559 X 1 -0.125    0.000  -2.5592E-01    2.0459E+00
```

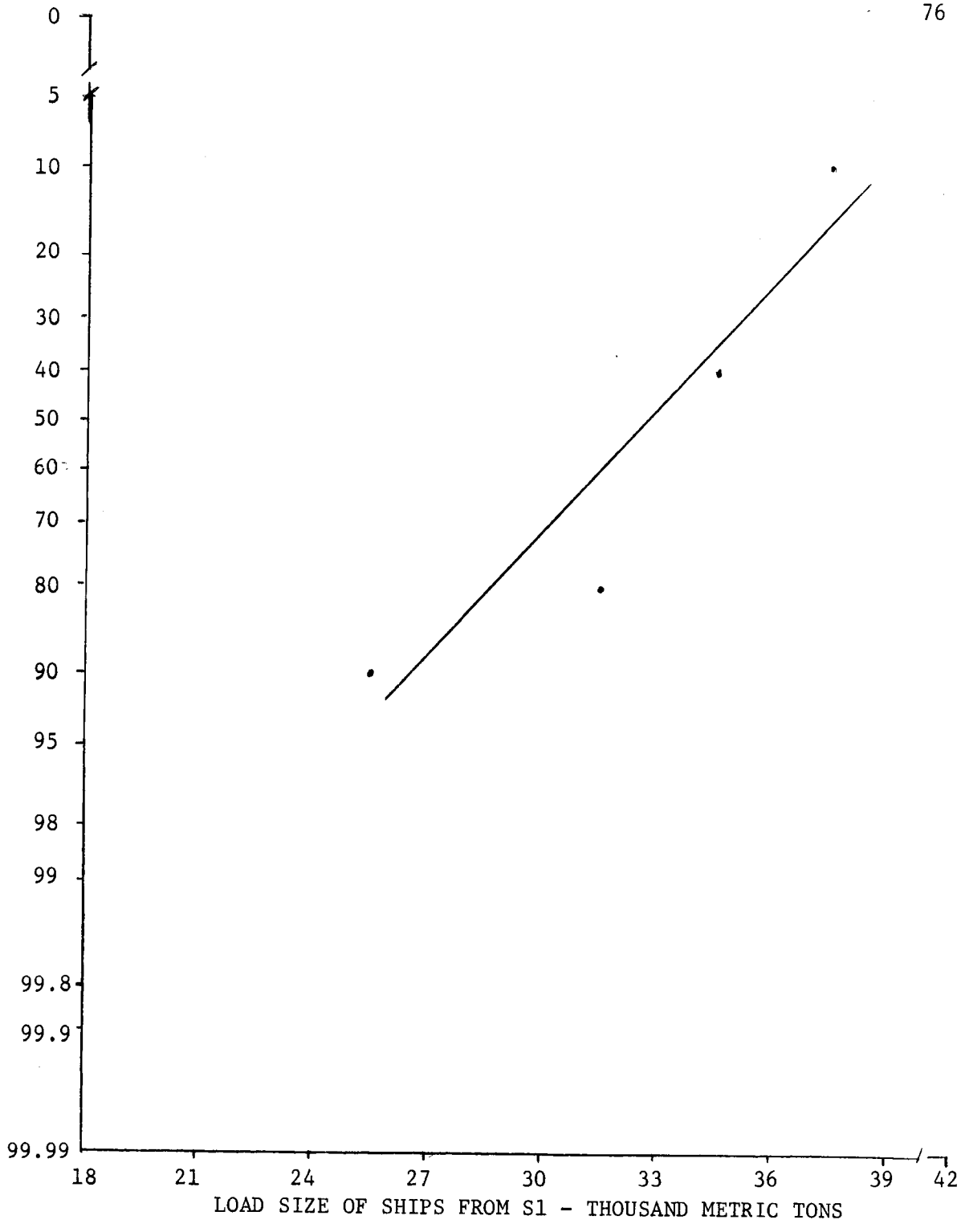


Figure 11. Distribution normality test for load size of ships from S1.

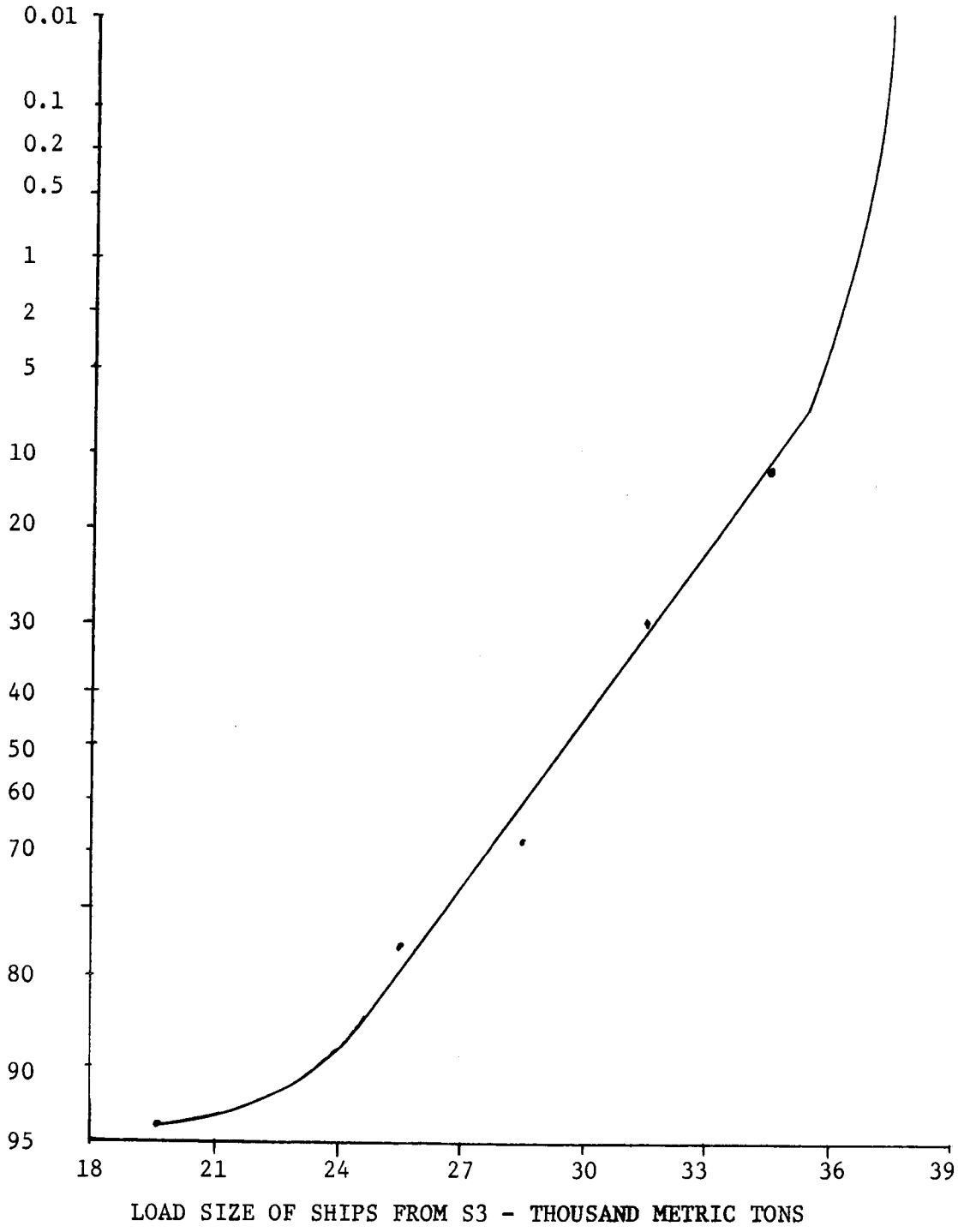


Figure 12. Distribution normality test for load size of ships from S3.

DEPRECIATION AND AUTHORIZATION EXPSENSE WORKSHEET
(all amounts in thousands)

Depreciation of Asset Groups by Sum-of-Years'-Digits Method

Year	Total Deprec.	Total Income Tax Deduction @ 48 Percent Tax Rate
1		
2	133.33	64
3	123.81	59
4	114.29	55
5	104.76	50
6	95.24	46
7	85.71	41
8	76.19	37
9	66.67	32
10	57.14	27
11	47.62	24
12	38.10	18
13	28.57	14
14	19.05	9
15	9.52	5

CASH FLOW AND PRESENT VALUE SCHEDULE
(all amounts in thousands)

Years	Tax Deduction From Deprec. and Expense	Investment Expenditures	Net Cash Flow	Discount Factor (a)	Present Value
1		-1,000	-1,000	.953	-953
2	64			.867	56
3	59			.788	47
4	55			.716	39
5	50			.651	33
6	46			.592	27
7	41			.538	22
8	37			.489	18
9	32			.445	14
10	27			.404	11
11	24			.368	9
12	18			.334	6
13	14			.304	4
14	9			.276	2
15	5			.251	1
			Net Present Value (End of Useful Life)		-664

(a) Based on Cost of Capital Rate of 10 Percent. Net Present Value of Tank to be Recovered in Years 2-21 is -$664,000. To Find the Compound Amount of -$664,000 at Start of Year 2 = -$664,000 (1+.10) = -$730,000. To Convert this Amount to be Recovered from After Tax to Before Tax = $\frac{\$730,000}{.52}$ = $1,400,000.

To Determine Annual Before Tax Savings Needed Over 20 Year Period = $\frac{\$1,400,000}{.11746}$ = $165,000.

VITA

Jimmy Bruce Whitchurch was born in Nowata, Oklahoma, on July 23, 1930. He attended elementary schools in that city and was graduated from Nowata High School in 1948. He then entered Oklahoma State University where, after an interruption to serve in the United States Army during the Korean Conflict, he received a Bachelor of Science degree in June, 1955.

Upon graduation he went to work for the Aluminum Company of America at their Rockdale, Texas Works as an Industrial Engineer. He has since served in various Industrial Engineering assignments at Alcoa's Point Comfort, Texas Operations and Alcoa, Tennessee Operations and is currently working on the Industrial Engineering staff at Corporate headquarters in Pittsburgh, Pennsylvania.

He entered the Graduate School of the University of Tennessee in March, 1967 and received the Master of Science degree in Industrial Engineering in March, 1973. He is a member of the American Institute of Industrial Engineers, and a registered professional engineer in the State of Oklahoma.

He is married to the former Elizabeth Elaine Albert of Rosebud, Texas.