DYNAMICS OF THE TANKSHIP INDUSTRY

by

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of the Requirements for the

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ABSTRACT

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The world oil tankship industry has a decided history of severe cyclical behavior. The object of this thesis is to investigate the nature and causes of such quantitative behavior. It is realized that such behavior stems from the basic organizational relationships and management decisions in the various parts of the industry. It is further realized that such behavior is fundamentally dynamic in character, and therefore the method of investigation used is industrial dynamics. In this method, a mathematical model is built up from descriptive knowledge of the causal relationships and functions existing in the situation under study.

A model was formulated which included seven sectors, covering most of the considered significant interactions and determinants of behavior. The role of expectations in the decision-making process was incorporated. The model simplified from the real world in many instances, and is based on certain assumptions stated. In spite of the simplifications, assumptions, and omissions, the behavior of the model, as shown in computer results, is in general quite reasonable compared to what would be expected in the real world. It has thus been shown that industrial dynamics is not only a valid tool for this investigation, but can yield highly rewarding results.

It is concluded that the new tanker ordering decisions are extremely important in stimulating the cyclical behavior. These decision rules should be revised further to improve the reasonableness of system behavior. Time did not permit this author to proceed in this direction beyond an outline of the very next steps involved.

The model presented herein can serve as a foundation structure upon which to develop more fully this area of investigation, and as a guide in such development. It is hoped that further work is carried out towards gaining a sounder understanding of the tankership market cycles.

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This work was done in part at the Massachusetts Institute of Technology Computation Center, Cambridge, Massachusetts, on the IBM 704, and their cooperation is appreciated.

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I. INTRODUCTION

The world tankship industry has long been known to go through severe cyclical fluctuations. In general terms, we see short periods of extreme tanker scarcity and excessively high freight rates, followed by longer periods of large tanker idleness and marginally low freight rates. The whole cycle usually lasts from four to five years. In the depression period, when there is marked overcapacity in the industry, there is, of course, little incentive for tanker owners to increase their fleet size. However, in the boom, when there are not enough tankers to satisfy the demand,orders are placed for new construction at a high rate even though delivery time on these vessels may stretch three to four years into the future. Thus, the cycles seem to be self-perpetuating and inherent in the industry structure.

The purpose of this thesis is to analyze the qualitative behavior of the tankship industry, especially the cyclical phenomenon. The study will include a review of the major factors that control behavior and their influence on the total system.

The method of analysis to be employed is industrial dynamics. As a general description, one could say that "industrial dynamics is an analysis of the information-feedback characteristics of our industrial enterprises to show how the tendencies toward instability, the competitive relationships, and the forces of growth are affected by structure, policy (a source of amplification), and delays (in decisions and actions)." (2) Industrial dynamics starts with a knowledge of "descriptive management" and attempts to formalize what is known about the many parts of a company, industry, or economy. It is then possible to study the interactions of these parts with the entire system (which is the sum of all the parts). See references (3) and (4) for a more extensive discussion of the background and philosophy of industrial dynamics.

Once a background of information on the basic organizational structure, functional relationships, and management decisions is acquired, the next step is to express this knowledge in a precise manner; that is, to formulate a mathematical model that describes what you know about the system you are dealing with. The mathematical model should, as closely as possible, follow the descriptive knowledge without going into excessive detail where it does not seem to be warranted. The model will usually be quite non-linear, since the systems dealt with in the real world are hardly linear. "The closed-loop, information-feedback characteristics and the decision-making procedures are incorporated." "The formulation can deal with an unstable system if the world it represents is unstable. It can incorporate hundreds or even thousands of variables to achieve sufficient reality to be useful. The computation needed for solution is only proportional to the number of variables and lies well within the capability of today's computers." (4)

As implied above, once the model is constructed, it is solved for a specified length of time on a digital computer. It is usually started in a condition of (equilibrium) steady-state, and then disturbed. The system will then be excited and respond according to its inherent structure and composition. By making changes in the model and then having it again solved, or run, on the computer, we can study the effect of any parameter decision, or organizational change on system performance (response).

The Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, has developed an IBM 704 Program for generating dynamic models. By following specified procedures and formats, one need have no knowledge of digital computer programming in order to have their model run on the IBM 704. See references (5), (6), and (7) for full information on preparing one's problem for computer solution.

With all of the foregoing in mind, this thesis thus presents first information on the organization and policies of the tankship's industry, including an analysis of some past history. This is not only the basis for construction of the model, but also serves as a comparison to the computer results to insure that they are reasonable or to indicate the direction for improvement. Then the model is formulated, step by step, showing the dérivation of and assumptions implicit in, each equation. Results of computer runs are next presented with analysis of their significance to the main theme of investigation: what are the major determinants of cyclical behavior? Great care must be exercised in drawing conclusions from the results of computer runs. We are, in fact, only looking at a mathematical model and not the real world. Depending on how much faith we have in the model's similarity with the actual system, we can expand computer results to explanations of real world events.

Furthermore, we must realize that we are not looking for quantitative answers or predictions. We are trying to find quantitative behavioral patterns. We are looking for forces that control such overall qualitative actions.

II. THE TANKSHIP INDUSTRY

Fundamentally, the tankship industry derives its existence from the oil industry. It performs the function of transporting certain quantities of oil (either crude or refined products) between certain points. The necessity for this function is based simply upon man's demand for the use of oil and the fact that major oil-producing areas (Persian Gulf, Venezuela, U. S. A., etc.) are not necessarily coincident with major oil-consuming areas (U. S. A., Western Europe, etc.). It is obvious that the general growth of the industry is threatened from two sides: 1. the discovery of new sources of oil closer to consuming areas than present supply sources (such as discoveries in the Sahara by French interests and others), and 2. the advent of different means of transporting oil more economically than by oil tanker (such as oil pipeline, inflatable barges, or perhaps, air transports). It is fortunate, however, for the industry that the above-mentioned threats to the tanker industry's growth are factors that are frequently hampered by political pressures and are very slow to reach significant proportions. For a short general discussion of the present status, and historical development of the tanker industry, see reference (10).

Before going into a discussion of factors that determine system behavior, we must commence with the description of the broad industry structure and functioning. The demand for tankship services obviously comes from the oil companies which must supply their customers with refined products, or which must supply their refineries with crude oil. The supply of tankers is found in two quarters. The larger oil companies themselves have marine subsidiaries that operate vessels to partially meet their needs (about 35% of the world fleet). The remainder of the world's tankers are owned by independent companies whose profit comes from renting or chartering their vessels to the oil companies. The charter agreement can take on many forms, but two types of charters predominate. There is the ~~time~~ charter where the owners rent their vessels out for a certain length of time (from several months to as much as ten years), and receive payment as a monthly rental. There is also the voyage charter wherein the vessel is rented for only one voyage (or perhaps several) between specified ports, and the payment is on a per-ton-cargo-transported basis. See reference (8) for the exact nature of typical charter arrangements.

Usually, most of the independent owners' tankers will be on time, or a long-term charter. Thus, the oil companies actually have a substantial part of their tonnage requirements heavily committed; that is, either owned or on a long-term hire. It is in the voyage charter market (spot market) where the excess, so to speak, demand is met and quick changes in plans can be accomodated. This demand, together with a given, rather inflexible short-run supply schedule determines the existing voyage charter freight rate (dollars per ton).

The supply and demand sides are brought together by the tankship broker. The brokers take a certain request for tonnage from the oil companies and seek an owner who can accomodate the specific requirements. A charter agreement is then signed which fairly well delineates the responsibilities and rights of both parties involved. On the date specified by the charter agreement, the vessel will commence operations and continue as long as is agreed upon.

Both the independent owners and oil company marine divisions order, as they so decide, new tankers from the shipyards of the world. The shipyards build only on order; they do not keep any stock or inventory on hand. Orders may be cancelled, with the penalty depending on how much work had been done on the contract, and the details of the arrangements made. Of course, as new vessels are delivered, older ships which are no longer economical to operate (this depends on the freight rate available to them) are scrapped; that is, sold as scrap iron.

Though the basic organizational framework of the industry is not overly complicated, the decisions which drive it onward are often motivated through nebulous means. Perhaps the most important motivation, in many of the important decisions, is that of freight rates or market expectations. What will be the condition of the market so many months, or years from now? This expectation is a major determinant in the decisions to order new ships, as well as to scrap existing vessels. For example, if a high freight rate is foreseen, independent owners will order new tankers and avoid scrapping as much as possible, to have many ships taking advantage of the high rates. Oil company marine divisions will also order new vessels and put off scrapping both to avoid having to pay such high rates and also to meet their heavy demand. In this respect, the large oil companies, of course, do not especially like high freight rates, but neither do they favor very low rates. Even though the cost of transportation is but a small fraction of the final price of oil, such low rates encourage the small oil companies, or "outsiders", who depend primarily on chartered tonnage, to attempt price cutting. If they do not cut their prices, their profits are greatly inflated since they can take advantage of the low freight rates to a greater degree than the larger oil companies. In a market boom period, however, the smaller companies which do not have much of their requirements filled by long-term charters, are severely hard-pressed indeed. Thus, the large oil companies must be careful in their policies for fleet expansion or they may create a market condition they find distasteful.

Expectations also exert an influence on chartering. The oil companies attempt to keep a balance between voyage and time charters that they deem favorable. If a scarcity of tankers is foreseen in the near future, they may try to cover more of their demands with time charters. There may thus, be many different expectations looking into the future by varying amounts of time.

Other motivations, besides market expectations, also have some significance. Financial considerations are a part of every decision. Large tankers represent heavy capital goods investment (as high as $25 million per vessel). Financing such purchases pose problems for both the independent owner and the oil company marine divisions. Obviously, before charters are signed,both parties consider seriously the financial aspects of the arrangement and possible alternatives.

Some of the very typical considerations of most industries, however, are not found in the tanker industry. Product quality, or in this case, service quality, is extremely uniform. Differences between vessels in speed or flexibility are reflected closely in the freight rates. Marketing, or sales effort, is on a very informal basis directed at either brokers or oil companies. As in any industry, certain trade connections are made which prove lasting, but in general, the market is highly competitive, with the lowest bid getting the charter. There is no organized market, however, but only the brokers who may, in an effort to secure specific tonnage, contact other brokers and thus create a sort of limited marketplace. Advertising is unheard of in the industry. Research and development activity is on an absolute minimal scale. Technological progress is stimulated predominantly in military areas. The recent tremendous increase in the size of tankers (the largest tanker afloat today has a capacity of about 100,000 long tons of oil, over six times as great as that of the largest World War II tanker) is not so much a technological advance, as an operational advance. The technical knowledge to build such large ships is not new, but the realization of their economic advantage is.

Perhaps allied to the financial motivation, but in a sense quite different, is the idea of speculation. Should an independent owner put all of his vessels into long-term charters that pay reasonable returns and thereby gain security, or should he "play" the voyage market, taking the ups with the downs, hoping that soon another boom will prove him right? All the independents, and there are many small firms involved (the largest independent owns 3.7% of the world fleet), have their own opinions. None follows one extreme or the other. There are some heavily committed to the spot market. Others are reluctant to order a new vessel without first having secured at least a five-year charter in advance.

It becomes clear, after some exposure to the industry, that policies and decisions are not only based on predictions of the future, but must be designed around such predictions. Major decisions have far reaching effects into the future. Predictions which are supposed to influence decisions are not only in themselves extremely rough, but further altered by the very decision it has led to. Individual owners or oil companies cannot plan the industry's future, but only hope to meet their own objectives. What may be the best policy for an individual owner or oil company, may not be best for the industry as a whole when it is followed extensively. Decision-makers find it hard to remember that the pattern of the industry has always been cyclical when they are in the midst of another boom. In the depression periods, the next boom is never in sight.

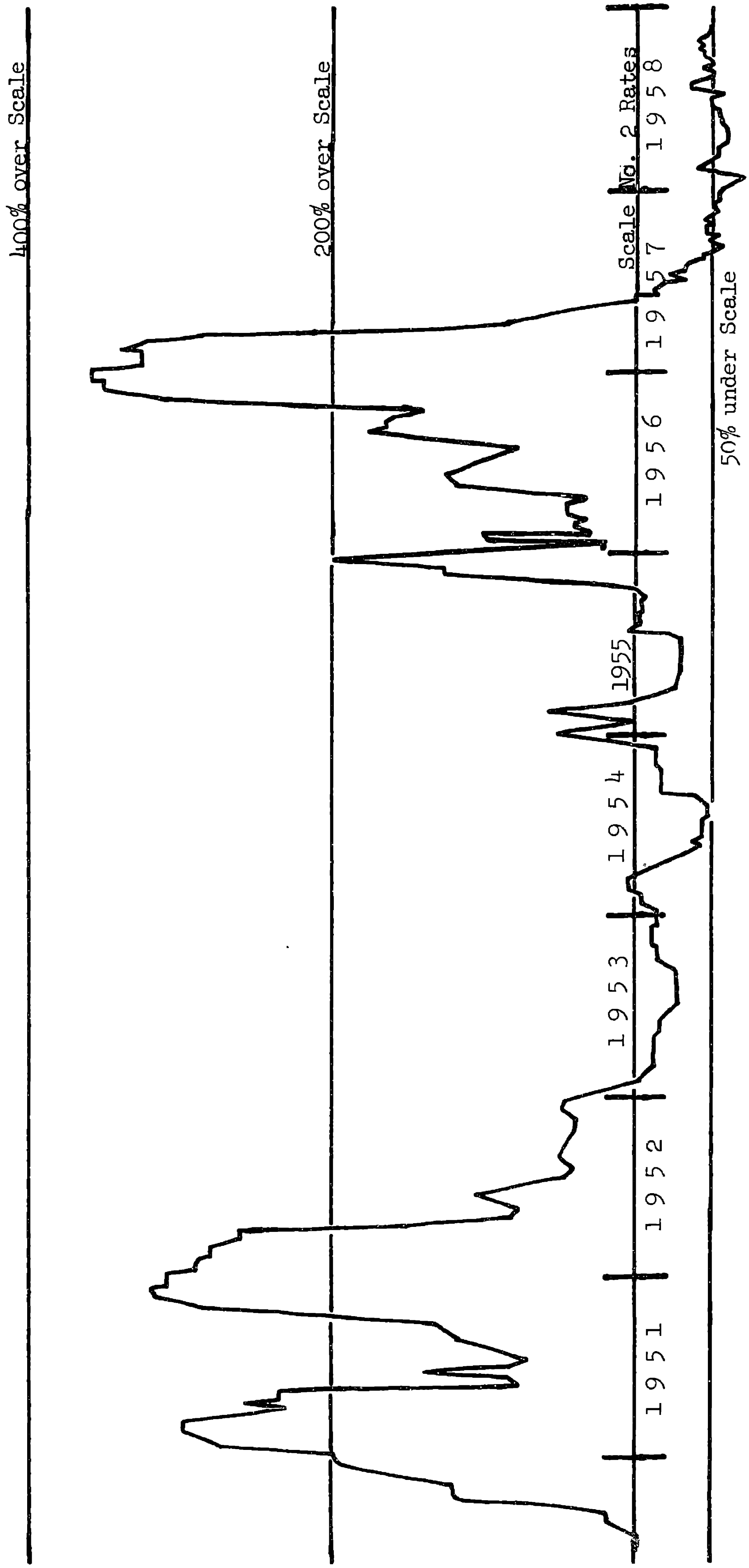
For a more detailed description of the important considerations in the industry, see references (1) and (13).

It would be well at this point to look at some of the recent industry history. Not only should this prove enlightening in itself towards an understanding of the industry, but should also serve as a yardstick against which to measure model behavior. At the very least, the model should resemble the industry behavior in general terms. Figure I is a plot showing voyage freight rate between 1951 and 1958. Freight rates are quoted customarily as percentages over or under scale. The industry has adopted, as a convention, what are known as "Scale No. 2 Rates". The scale rates specific a freight rate, in shillings per ton (London market), for many trade routes. When established in 1954, they were supposed to represent fair prices based on average costs and profits. Whether they still have such significance is a moot point, since they are predominantly used merely as a convenient measure of freight rates, not only between different points in time, but also between different routes. Figure I then, shows an estimated voyage rate over various routes for a common size of vessel (these rates are for cargos of crude oil, referred to as "dirty", as opposed to refined products, "clean"). It can be clearly seen that the industry went through a complete cycle from 1951 to about 1956. The cycle is not a smooth one (sinusoidal), but rather quite flat in the depression periods with sharply defined periods of extremely high freight rates. It is obvious that the industry does not move gradually from boom to depression periods. Within a few months, which is short compared to the four- or five-year cycle period, the market can go from an extremely

Figure I

Estimated Tanker Market Rates - Single Voyages (Dirty)

Based on fixtures 9/18000 tons in various directions

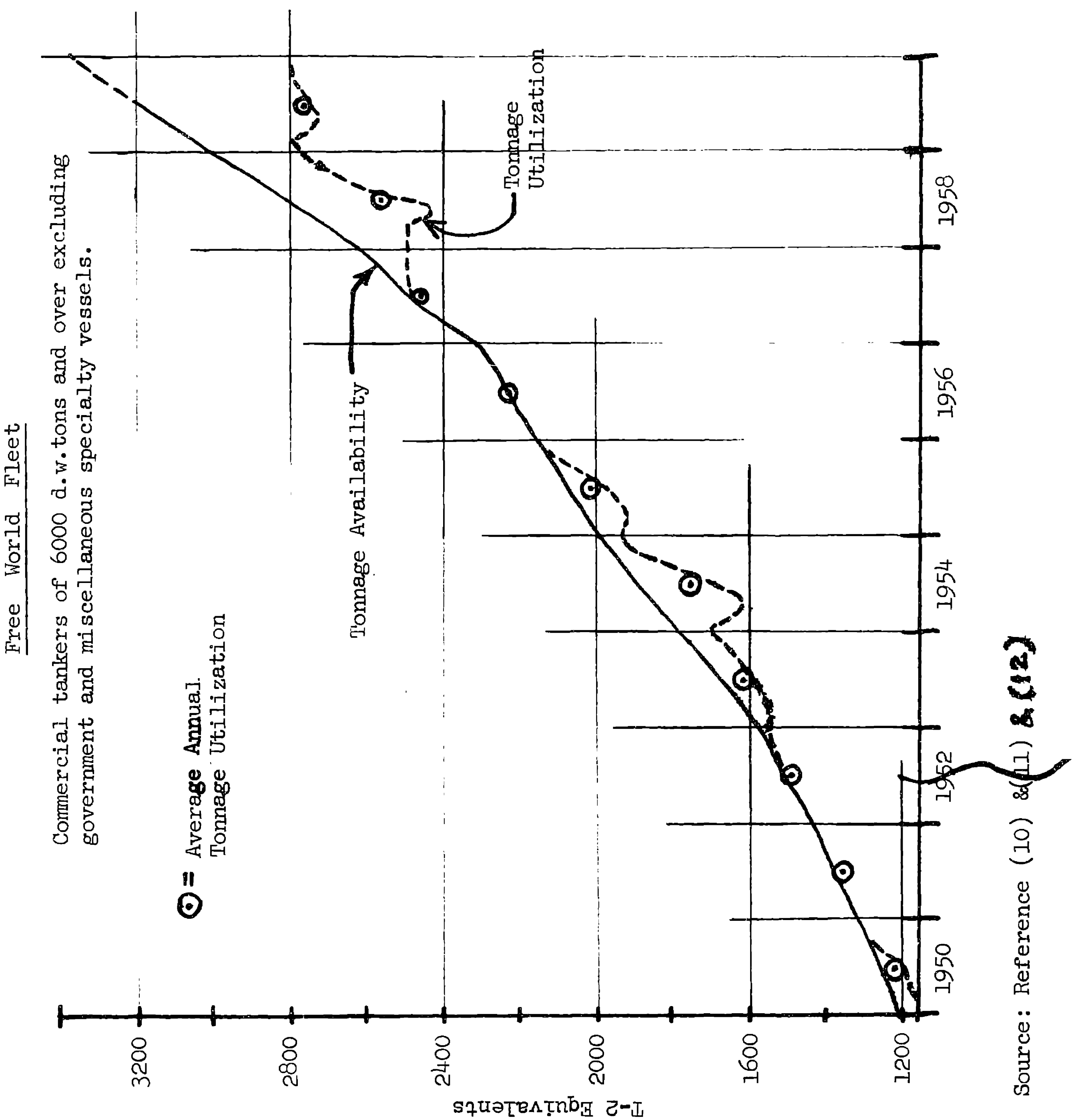


Source: Conrad Boe Ltd. A/S, Shipbrokers, Oslo, Norway high rate to a very low rate (see 1957). It should also be noted that the boom periods have occurred at times when the demand may be considered to have been especially heavy. The Korean War (1950 to 1952) and the closing of the Suez Canal (late 1956 to 1957) certainly imposed excessive strains on the tankship industry. However, these strains should not be overly exaggerated. The oil companies have been able, in such situations, to effectively rearrange their supply and route structure to meet the situation. Certainly such exigencies tighten the market, but it is not so certain that they completely cause cyclical behavior. For example, the last boom started at the end of 1955, well before the Suez crisis. The cyclical behavior seems to be inherent in the industry structure, with temporary crises acting as the trigger to accentuate the pattern.

In Figure II we see what lies behind the freight rates. The solid line shows the tonnage available over the period from 1950 to 1959. It is measured in "T-2 Equivalents" which is used to express the sum of the many different tankers on a common basis. The T-2 is a ship design developed prior to World War II. During the war over 500 of these ships were built and they have become a common reference point. They have a speed of 14.6 knots and a deadweight capacity of 16,600 long tons (deadweight tons - dwt) is a measure of the total variable weights on a ship and include, in addition to cargo, fuel, stores, and crew and effects). (A T-2 can carry about 15,200 tons of cargo oil.) Thus, a vessel of different speed and deadweight can be expressed as so many T-2 equivalents, i.e., a tanker with a speed of 16.6 knots and 29,200 dwt, would equal (16.6/14.6) x (29,200/16,600) = 2.0 T-2 equivalents.

While the solid line shows available tonnage, the small circles

Figure II



Source: Reference (10) & (11) & (12)

show the average annual tonnage utilization and the dashed line shows the approximate pattern of tonnage utilization over the time period covered. It can be noted that those periods where available tonnage exceeds that utilized, which means that the difference represents idle tankers, correspond to periods of depressed freight rates. Idle tankers, however, do not always indicate the complete market condition. Vessel slow-down (which also saves fuel costs), increased time for ship repairs and overhauls, and inefficient ballast voyage arrangements can add further to the effective surplus amount of tonnage. Just as well, in times of need, the opposite of such measures adds considerably to the effective tonnage in operation.

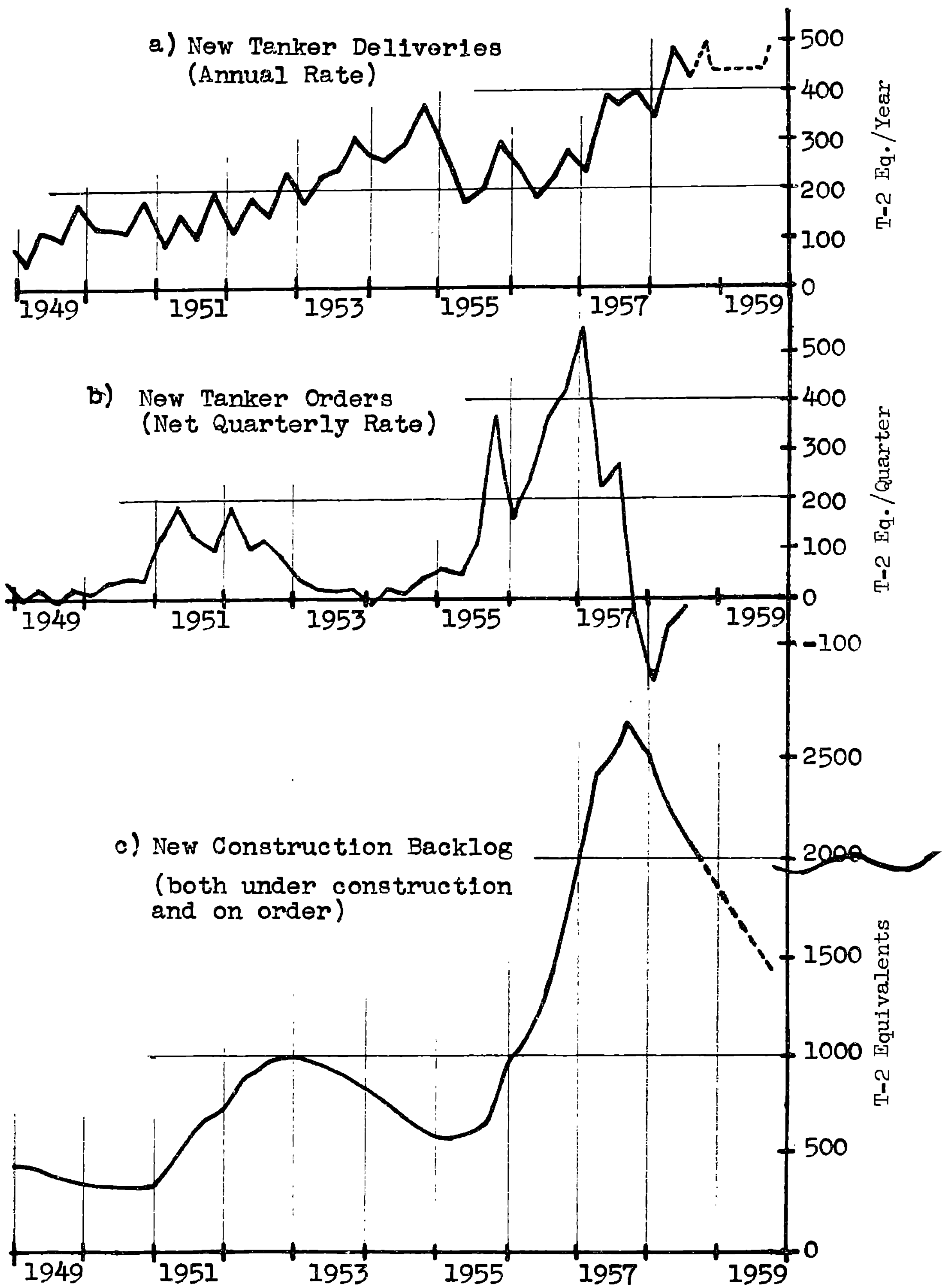
It may also be noted that when oil companies can plan requirements closely, that is, when a surplus exists which allows a certain flexibility, the utilization pattern follows a seasonal pattern. In the fall and winter months, oil demand (from consumers) is highest and consequently requires greater-than-average tanker shipments. When at all possible, the oil companies will attempt to gauge their tanker usage closely, so as to reduce storage and other costs to a minimum.

The basic trend of tonnage utilization as shown in Figure II is intimately related to the increased world demand for oil and the location of supply points relative to consumption areas. Oil consumption has been increasing over the years. This, in turn, has influenced supply patterns, for the increased amounts of oil have had to come from more distant points. Since 1950, oil demand has increased an average of about 6.5 per cent per year while tankship utilization has increased an average of about 9.5 per cent per year. As far as the tanker industry is concerned, however, it is not felt that oil demand or supply orientation are substantially affected in the long run by tankship market developments. Such areas are considered beyond the scope of this endeavor.

Figure III presents some statistics of the shipbuilding industry which, of course, is closely related to the tankship industry. Figure IIIa shows the rate of new tanker deliveries from 1949 to 1959. Aside from the short-term fluctuations there appears to be a cyclical pattern. This is due, naturally, to the rate of new tanker orders received, which, as shown in Figure IIIb, is severely peaked at two points of time. The high order inflow builds up the new construction backlog, Figure IIIc, which stimulates increased production effort which, in turn, leads to a high delivery rate. The delay involved, however, is considerable, about two to three years, and acts to aggravate the tanker market. For example, the large amount of orders placed in 1956 and 1957 will undoubtedly produce record delivery rates in 1959 and 1960, which come at a time when the market is already deppessed and there is a huge surplus of tonnage. This burst of orders came at a time when the market was extremely high, but how justified was the belief that such a condition would last much longer? The backlog in 1957 was about equal to the total fleet. Such a condition should have been ample warning of the impending market reversal.

In reviewing the organization and decision structure, and the past history, of the tankship industry, it becomes clear that it is an extremely difficult task to formulate such knowledge into analytical statements that are really significant and plausible. The attempt at such formulation that follows is not to be considered the final answer at all, but more like the first preliminary trial. It is expected that many areas of the model will need overhaul. Modifications, additions, and major revisions are only natural in the development of a model such

Figure III



Source: Reference (9) & (11)

as this. The next chapter will explain the formulation of the model as originally conceived, and any revisions that time permitted this writer to undertake.

III. DESCRIPTION OF THE MODEL

The original model was formulated with the intent of only providing a basic foundation upon which further work might build. It was early decided that flows of both manpower and materials were not major factors in the industry and could, therefore, be omitted from the model, since we shall attempt to include only the most important determinants of behavior. Financial considerations also, have been omitted though at times they are significant. It was felt that in looking at the entire industry, the aggregate of all the individual firms, financial considerations were not of first-order magnitude. The system, therefore, consists of only flows of capital goods, orders, and information.

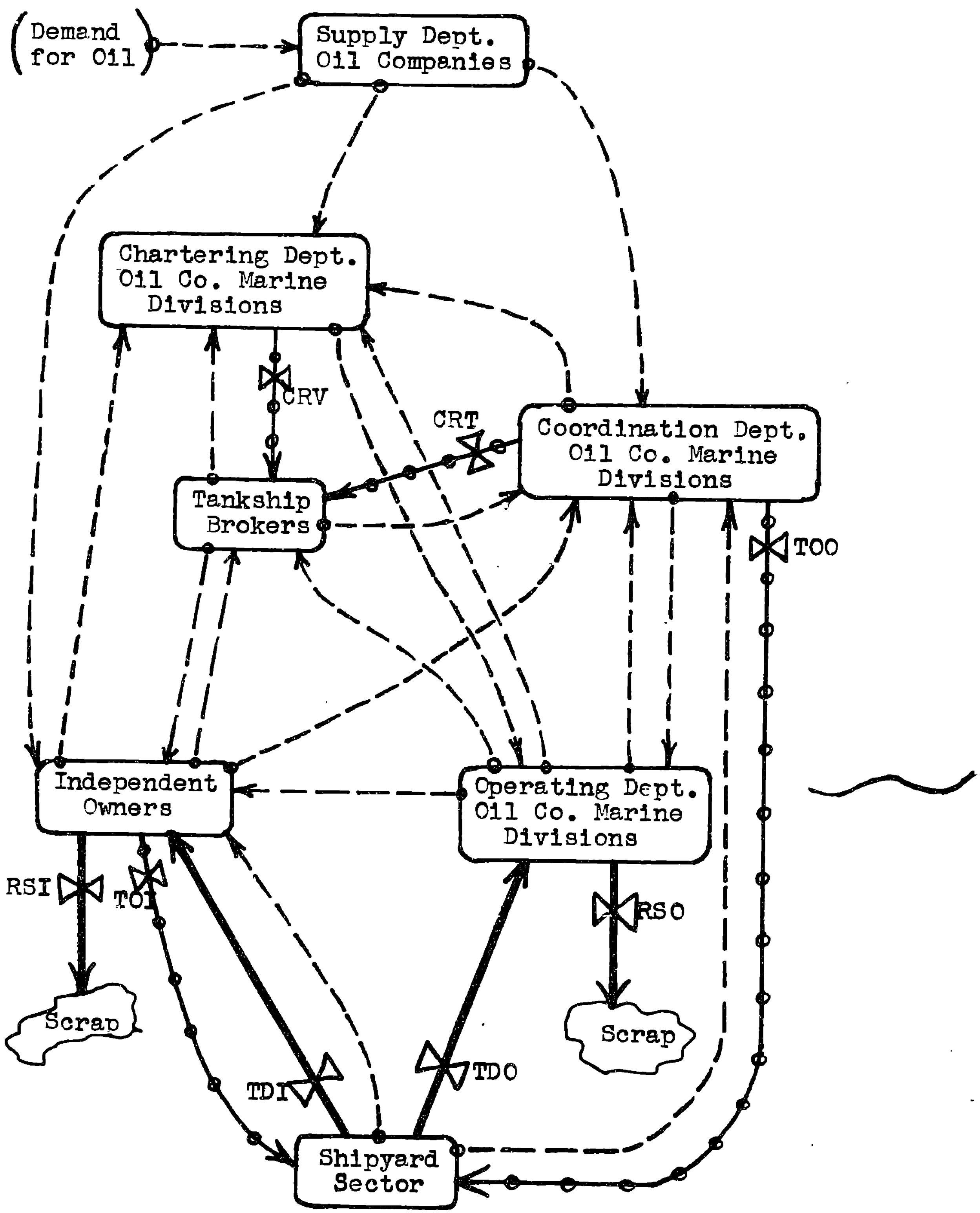
Other factors that have some bearing on the industry but which for the present work have not been included, are technological changes, changes in ship size, and governmental restrictions. These should be included in a more complete model but were not felt to warrant initial consideration. It was not felt that these factors exert major forces on the inherent industry behavior in the long run. Later inclusion of these factors might prove highly interesting.

One point should be borne in mind in going through the development of the model. That is, any part of the formulation that is not thought to be reliable can be tested. By formulating that part in what is thought to be a more reasonable form, and then looking at the new computer results, we can determine not only the importance to over-all system behavior of this part, but also the relative difference between the two formulations.

Figure IV is a flow diagram for the over-all system. It shows

Figure IV

Overall System Flow Diagram



the seven sectors of the model and the main flow of information, orders, and capital goods (tankships) among them. Information flows are the dashed lines, orders are the lines with small circles, and capital goods are the heavy solid lines. Rates of flow are indicated by small valve symbols. In general, the model attempts to follow actual behavior, even where such may be simplified, for greater clarity and coherence.

The external input to the model, shown on the upper left of Figure IV, is the short-run demand for oil. This demand goes to the supply departments of the oil companies which must see that the many refineries and consumers are adequately supplied. The supply department, therefore, translates this demand for oil into a demand for the transportation of oil. In addition, it also establishes predictions as to the future demand for oil. The chartering department of the oil company marine divisions receives the demand for tankships and decides upon a rate of voyage chartering to meet this short-run demand (CRV). The operating department of the oil company marine divisions is set up to keep account of, and transfer as required, the oil company's own tanker fleet. It, therefore, receives new vessel deliveries from the shipyards (TDO) and discards vessels for scrap (RSO). The independent owners sector not only keeps account of the independently owned fleet, but also generates the major decisions of that segment of the industry. Orders for new construction are sent to the shipyards (TOI) and vessels are received (TDI), as well as scrapped (RSI).

The tankship brokers sector receives the orders for both voyage charters (CRV) and time charters (CRT). When these charters are to go into effect, the appropriate rate of vessel transfer is instituted. The brokers also determine the voyage freight rate and its apparent rate of change. It then generates a long-run predicted freight rate. The coordination department of the oil company marine divisions generates the major policies and decisions of that part of the industry. The rate of new construction is established (TOO) and the scrappage rate also determined here (RSO). The rate of time chartering (CRT) is decided here based on long-run policy considerations. The last sector, the shipyards, receive new construction orders and proceed to generate tanker deliveries to both the independent owners and oil company marine divisions.

Intertwined among all the sectors is a flow of information which makes the behavior of each sector dependent on the other sectors, to a more or less degree according to the relationships involved. Each sector, however, will be described separately.

A. Supply Department

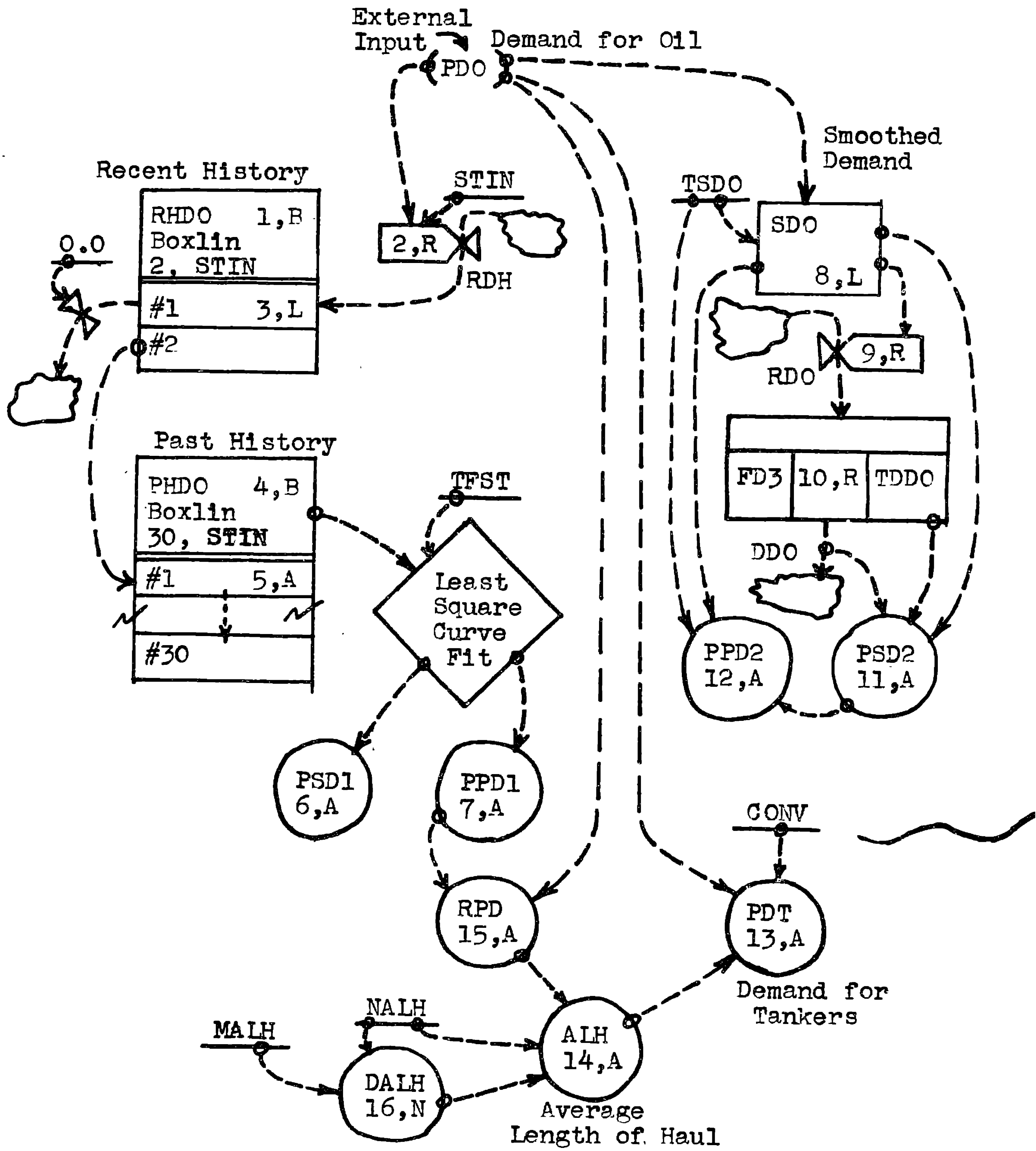
The supply departments of the oil companies receive the external input to the system, the demand for oil. This is the amount of oil that consumers and refineries want three months from the present. The first function to be incorporated into the supply department will be the basis for extrapolation of past history into the future. This will be done by fitting a straight line to the data of the past. This data is accumulated and stored in linear boxcar trains. A linear boxcar train holds a number in each of its boxcars and periodically shifts them to the next car and sets the first car to zero. The value in the last car is lost. See Figure V for the flow diagram of this sector.

RHDO = BOXLIN (2, STIN) (1,B) where RHDO is Recent History of Demand for Oil.

STIN is Shifting Time INterval, months. This equation sets up a

Figure V

Supply Department Flow Diagram



linear boxcar train, called RHDO, which has two (2) boxcars whose values are shifted every STIN months. In the first car we will accumulate data, while the second car (last interval's value) will be stored in another boxcar train.

RDH.KL = PDO.K/STIN (2,R)

RHDO*1.K = RHDO*1.J + (DT)(RDH.JK) (3,L) where RDH is Rate of Demand History accumulation, bbls/day/month.

PDO is Present Demand for Oil, bbls/day (external input).

STIN is Shifting Time INterval, months.

RHDO*1 is first boxcar in RHDO, bbls/day.

DT is solution time interval, months.

Equation 2,R transforms the demand into a rate building up the level of the first boxcar, RHDO*1. At the end of STIN months its value will be the arithmetic average of PDO over the interval, and will be shifted into the second boxcar.

PHDO = BOXLIN (30,STIN) (4,B)

PHDO*1.K = RHDO*2.K (5,A) where PHDO is Past History of Demand for Oil.

PHDO*1 is first boxcar in PHDO, bbls/day

RHDO*2 is second boxcar in RHDO, bbls/day.

The boxcar train, PHDO, stores the average values of demand for the past thirty intervals. It does not include any data of the present interval. At the end of the present interval, the average value of demand goes into RHDO*2, and, therefore, into PHDO*1 also, while the value of the previous interval goes into PHDO*2, and so on.

Given the average values of the demand over the past, and TFST, the time period for fitting a straight line to the data, we can proceed by the method of least square errors to get the best fit of the data with a straight line. The details of this procedure are outlined in Appendix A. We can simply write:

PPD1 = generated by least square technique (6,A)

PSD1 = generated by least square technique (7,A) where PPD1 is Predicted Present Demand, bbls/day.

PSD1 is Predicted Slope of Demand, bbls/day/month.

The last two variables have ones after them because another method was also used to generate such predictions. The second method first smooths the demand, PDO, then delays it, and compares the inflow and outflow of the delay to determine the slope.

SDO.K = SDO.J + (DT/TSDO)(PDO.J - SDO.J) (8,L) where SDO is Smoothed Demand for Oil, bbls/day.

TSDO is Time period for Smoothing the Demand for Oil, months.

This is the usual smoothing equation which gives an exponentially weighted average of all past values of PDO. That is, the most recent value is given most weight, while those further back get much less weight.

RDO.KL = SDO.K (9,R)

DDO.KL = DELAY 3 (RDO.JK, TDDO) (10,R) where RDO is artificial Rate for extrapolating PDO.

DDO is Delayed value of RDO

TDDO is Time constant in delay for DDO, months. The smoothed value is here used as a rate into a third order exponential delay. The smoothed value may be visualized as lagging behind the actual value by TSDO months, while the delayed value lags behind the smoothed value by TDDO months. Thus, we can write:

PSD2.K = (SDO.K - DDO.JK)/TDDO (11,A)

PPD2.K = SDO.K + (PSD2.K) (TSDO) (12,A)

The predicted slope is based on the difference between input and output of the delay, while the predicted present value is the smoothed value extrapolated to the present. The system will use the least square predictions in further instances, but it will be interesting to compare the results obtained by such two completely different techniques.

The supply department must then translate the demand for oil into the demand for transportation.

PDT.K = (PDO.K) (ALH.K) (CONV) (13,A) where PDT is Present Demand for Tankers, T-2s.

ALH is Average Length of Haul, miles

CONV is CONVersion factor, T-2/bbl-miles/day.

The demand for tankers is related to the demand for oil and the average distance it must be transported. The factor, CONV, changes the units from bbls-miles/day into T-2 equivalents.

The average length of haul is a vital factor in tankship use. The oil companies are constantly searching for sources of oil that are close to consuming areas, thereby reducing the tanker voyage required. Also, the construction of many more refineries cuts down on haulage of oil in general, and thereby would reduce the factor ALH, since it refers to the average haul for all oil used, not only the part that must be transported by tankers. On the other hand, however, the continued increase in oil demand has usually meant that a good portion of the extra demand has depended on longer tanker voyages. For example, if we assume full use of the closest sources and partial use of farther sources at any point in time, increased demand without the corresponding increase in close sources will lengthen the average haul. The effects of average haul length are felt especially in the short run, where new sources cannot be opened up quickly, while long-run effects, though extremely significant for the industry, take affect very gradually. Therefore, we shall only try to set up the former effect, leaving the long-run changes to further work. It is not felt that such omission will have any great significance on inherent system behavior.

ALH.K = MALH + (DALH) (RPD.K) (14,A)

RPD.K = PDO.K/PPD1.K (15,A)

DALH = NALH - MALH (16,N) where MALH is Minimum Average Length of Haul, miles.

NALH is Normal Average Length of Haul, miles.

RPD is Ratio of actual to Predicted Demand.

This establishes ALH as a linear function of the ratio of actual to predicted demand. If the demand is higher than predicted, or expected, the average length of haul increases. If demand is down, ALH decreases. Admittedly, this is a rather rough approximation to an extremely complex area, but it is felt that it incorporates the major factors in a reasonable manner.

The values of the parameters of this sector in the original model were as follows:

TFST = 60 months

STIN = 2 months

TSDO = 30 months

TDDO = 30 months

That is, the curve-fitting process used all the data of the past five years. Similarly, there is in effect a five-year delay involved in the second method of extrapolation. Additionally, we have:

MALH = 3000 miles

NALH = 4000 miles

CONV = 0.00000003 T-2/bbl-miles/day

It should be remembered that the actual values of parameters are not necessarily critical to system behavior. Their significance can be determined through later tests before spending too much effort in refining their value now. If any parameter is critical, then its value can be determined more accurately, if necessary, or at any rate, system performance can be investigated relative to it.

B. Chartering Department

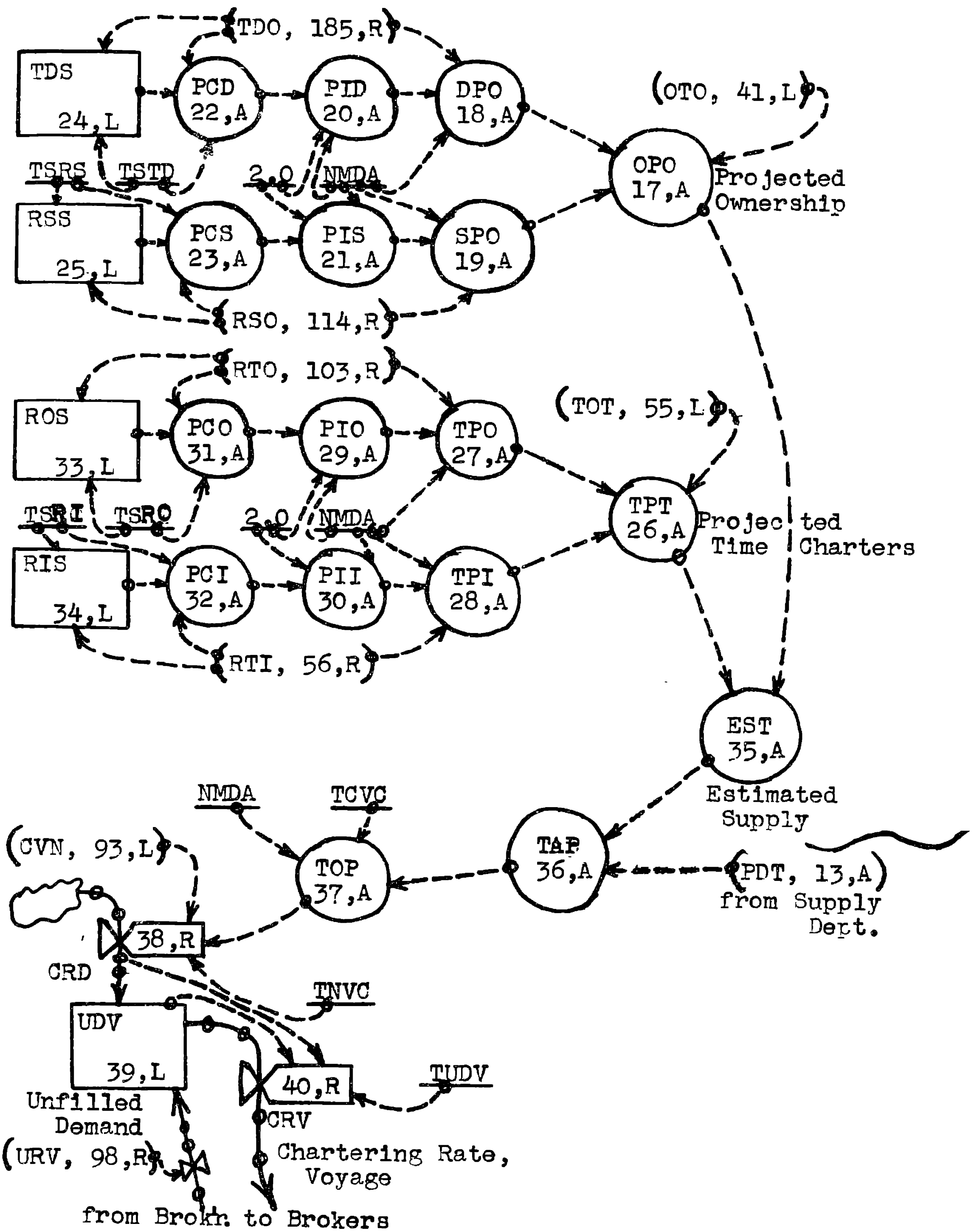
The basic function of the chartering departments of the oil company marine divisions is to determine how many tankers to charter on voyage to meet the demand received from the supply department. The approach is straight forward. Since the demand is for so many T-2 equivalents in three months, first estimate how many vessels the oil companys will own and have on time charter in three months. Compare this to the demand to establish the chartering rate, taking into account any previously made charters.

To estimate how many vessels the oil companies will own and have on time charter, estimates are made of the expected delivery rate of new vessels, scrappage rate of old vessels, and the rates of vessels going on and off time charter. All these rates are projected into the future through use of their smoothed values. These are the values that people are prone to look at when considering the future trend. They will look not at the present rate of change, but at the rate of change of the smoothed (or averaged) value. It is only natural to look at an average of past values to get a trend with which to extrapolate into the future. See Figure VI for the flow diagram of this sector.

OPO.K = OTO.K + DPO.K - SPO.K (17,A) where OPO is Owned tankers, Projected, of Oil companies, T-2s

Figure VI

Chartering Department Flow Diagram



OTO is Owned Tankers of Oil companies, T-2s

DPO is Deliveries, Projected, to Oil companies, T-2s

SPO is Scrappage, Projected, of Oil companies, T-2s

This equation merely adds the projected amounts of new deliveries and scrappage (negative) to the present oil company fleet, OTO.

DPO.K = (NMDA) (PID.K + TDO.JK) (18,A) where NMDA is Number of Months Demand is Anticipated, months

PID is Projected average Increase in Delivery rate, T-2/months

TDO is Tanker Delivery rate to Oil companies, T-2/months

Thus, the expected deliveries in the next three months (NMDA) is the present rate of delivery, plus the estimated average increase in delivery rate, times the number of months demand is anticipated, namely three. Similarly, we have:

SPO.K = (NMDA) (PIS.K + RSO.JK) (19,A) when PIS is Projected average Increase in Scrappage rate, T-2/months

RSO is Rate of Scrappage, Oil companies, T-2/months

We then have:

PID.K = (PCD.K) (NMDA) /2 (20,A)

PIS.K = (PCS.K) (NMDA) /2 (21,A) where PCD is Projected rate of Change in Delivery rate, T-2/months/months

PCS is Projected rate of Change in Scrappage rate, T-2/months/months

The rate of change that is expected in the delivery or scrappage rates is extended over half the estimating interval to get the average increase (or decrease) in the rates. It is implicit here that we are estimating a constant rate of change to hold over the period of projection.

PCD.K = (TDO.JK - TDS.K) /TSTD (22,A)

PCS.K = (RSO.JK - RSS.K) /TSRS (23,A)

TDS.K = TDS.J + (DT/TSTD) (TDO.JK - TDS.J) (24,L)

RSS.K = RSS.J + (DT/TSRS) (RSO.JK - RSS.J) (25,L) where TDS is TDO Smoothed, or average value of delivery rate, T-2/months

TSTD is Time period for Smoothing TDO, months

RSS is RSO Smothed, or average value of scrappage rate, T-2/months

TSRS is Time period for Smoothing RSO, months

These first two equations set up the projected rates of change as the rate of change of the smoothed, or average, values. The second pair of equations merely are those of the smoothed values themselves.

The same process of projection is used to estimate how many vessels will be on time charter in three months from the present. The equations are here set forth with no further explanation.

TPT.K = TOT.K + TPO.K - TPI.K (26,A)

RPO.K = (NMDA) (PIO.K + RTO.JK) (27,A)

TPI.K = (NMDA) (PII.K + RTI.JK) (28,A)

PIO.K = (PCO.K) (NMDA) /2 (29,A)

PII.K = (PCI.K) (NMDA) /2 (30,A)

PCO.K = (RTO.JK - ROS.K) /TSRO (31,A)

PCI.K = (RTI.JK - RIS.K) /TSRI (32,A)

ROS.K = ROS.J + (DT/TSRO) (RTO.JK - ROS.J) (33,L)

RIS.K = RIS.J + (DT/TSRI) (RTI.JK - RIS.J) (34,L) where TPT is Tankers, Projected, on Time charter, T-2s

TOT is Tankers On Time charter, T-2s

TPO is Tankers, Projected, to go On time charter, T-2s

TPI is Tankers, Projected, to go Idle off time charter, T-2s

PIO is Projected average Increase in RTO, T-2/months

RTO is Rate of Time charters going into Operation, T-2/months

PII is Projected average Increase in RTI, T-2/months

RTI is Rate of Time charters going Idle, T-2/months

PCO is Projected rate of Change in RTO, T-2/months/months

PCI is Projected rate of Change in RTI, T-2/months/months

ROS is RTO Smoothed, T-2/months

RIS is RTI smoothed, T-2/months

TSRO is Time period for Smoothing RTO, months

TSRI is Time period for Smoothing RTI, months

Now that these estimates have been made, they can be compared to the demand.

EST.K = OPO.K + TPT.K (35,A)

TAP.K = PDT.K - EST.K (36,A) where EST is Estimated Supply of Tankers, T-2s

TAP is Tankers Additionally required to meet Projected demand, T-2s.

PDT is Present Demand for Tankers, T-2s

This estimated supply is based on the assumption that none of the vessels presently on voyage charter will still be in operation (average length of time on voyage charter is 1.5 months), nor will any vessels go onto voyage charter (taken into account later).

Having established how many tankers are desired to be on voyage charter three months from the present (TAP), this must be converted into an appropriate chartering rate.

TOP.K = (NMDA) (TAP.K) /TCVC (37,A) where TOP is Tankers required to be Obtained to meet Projected Demand, T-2s

TCVC is Time, average, on Charter for Voyage Charters, months

NMDA is Number of Months Demand is Anticipated, months

This equation determines the number of tankers that should be obtained in the next three months to achieve the desired size of voyage charter fleet. This amount is then compared to the number of tankers that have been obtained already, but have not yet gone into operation under the charter agreement (the average lead time is two months).

CRD.KL = (TOP.K - CVN.K) /TNVC (38,R) where CRD is Chartering Rate, voyage, to meet Demand, T-2/months

CVN is Chartered tankers, Voyage, Not yet in operation, T-2s

TNVC is Time, average, available to Negotiate for Voyage Charters, months

Thus, this chartering rate attempts to fill the demand within the available time. This rate goes into a level of unfilled tanker demand (which is usually zero as long as there are enough available vessels).

UDV.K = UDV.J + (DT) (CRD.JK - CRV.JK + URV.JK) (39,L) where UDV is Unfilled Demand for Voyage charters, T-2

CRV is Chartering Rate, Voyage, actual, T-2/months

URV is Unfilled chartering Rate, Voyage, T-2/months

URV comes back to the chartering department from the tankship brokers whenever charters cannot go into operation because of lack of enough tankers.

CRV.KL = CRD.JK + UDV.K/TUDV (40,R) where TUDV is Time period in which it is desired to deplete UDV, months

This rate is sent to the tankship brokers. It implies that any demand that cannot be immediately met will be accumulated, as it comes back from the brokers, and will be desired again until it is eventually satisfied.

The values of the parameters of this sector, in the original model, were as follows:

NMDA = 3 months

TSTD = TSRS = TSRO = TSRI = 6 months

TCVC = 1.5 months

TUDV = 12 months

TNVC = 1 month

Thus, in making projections, it is an average of the rates over the last half year that are used. It should also be noted that the above values of NMDA and TNVC must be correlated to the average lead time, that is, lead time plus negotiation time must equal anticipation t[illegible].

C. Operating Department

This department keeps track of the oil company fleet. In addition, if at all possible, all the owned vessels of the oil companies will be employed as a statement of policy. This is regardless of costs that may be involved. Such a policy is instituted not only to keep the operating personnel on a more continuous basis, but also is advantageous from the point of funds flow and prestige. Such a policy could be changed later to study the effect on total system behavior. See Figure VII for the flow diagram for this sector.

OTO.K = OTO.J + (DT) (TDO.JK - RSO.JK) (41,L) where OTO is Owned Tankers of Oil companies, T-2

TDO is Tanker Delivery rate to Oil companies, T-2/months

RSO is Rate of Scrappage, Oil companies, T-2/months

This equation merely keeps account of the total oil company owned fleet.

ITO.K = ITO.J + (DT) (-ROT.JK) (42,L)

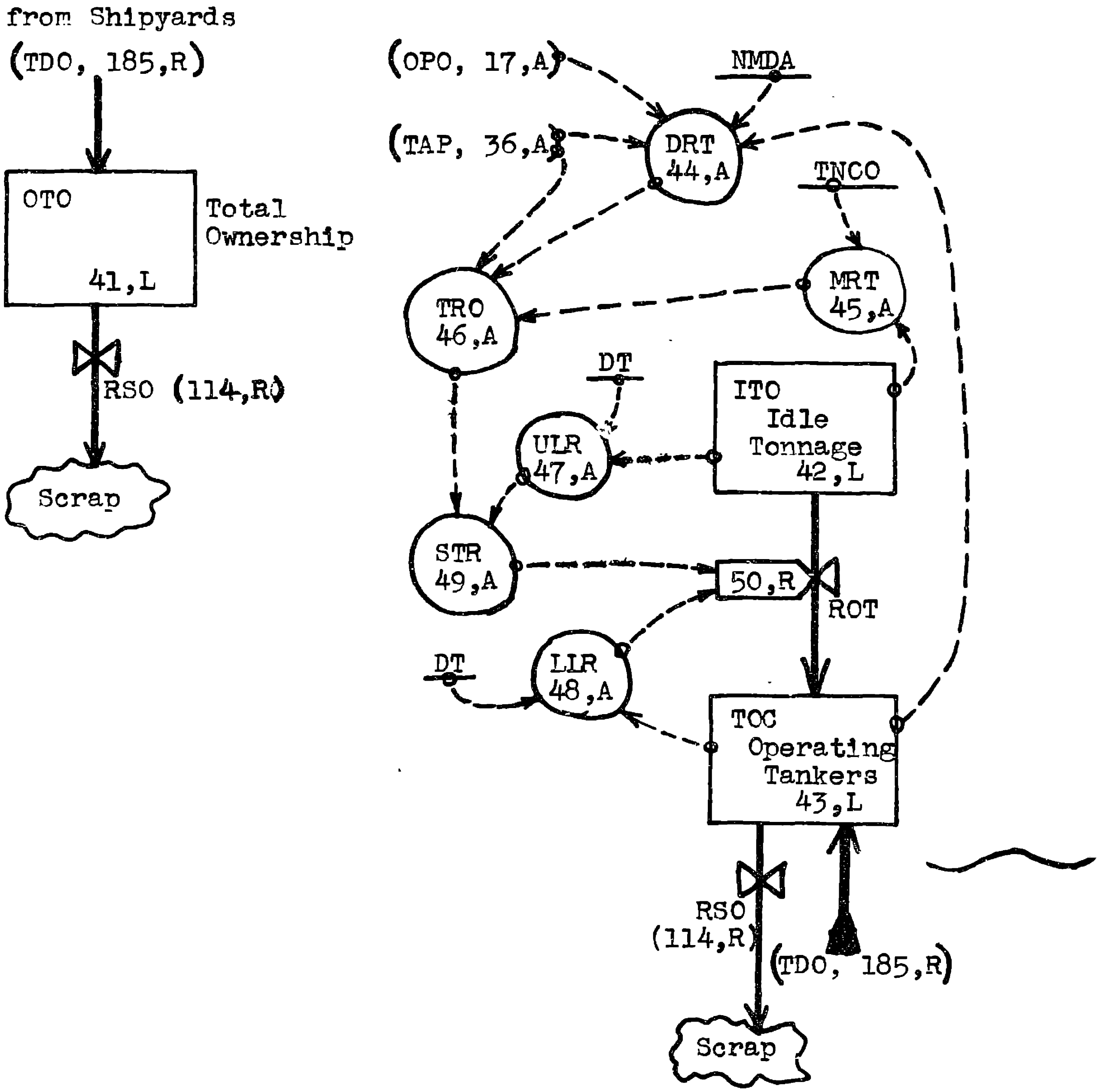
TOC.K = TOC.J + (DT) (ROT.JK + TDO.JK - RSO.JK) (43,L) where ITO is Idle Tankers, Oil companies, T-2

TOC is Tankers in Operation, oil Companies, T-2

ROT is Rate of oil company vessel Transfer, T-2/months

Figure VII

Operating Department Flow Diagram



These equations account for vessels idle or in operation. The rate of transfer will now be established in line with the above policy.

MRT.K = ITO.K/TNOO (45,A)

DRT.K = (OPO.K + TAP.K - TOC.K) / NMDA (44,A) where MRT is Maximum Rate of Transfer, T-2/months

TNOO is Time Needed to put vessels into Operation, Oil companies, months

DRT is Desired Rate of Transfer, T-2/months

The maximum rate is determined by the physical limit of how fast a vessel can be recommissioned. The desired rate is based on putting as many vessels into operation as can be used.

TRO.K = MRT.K, if TAP.K $>$ 0.0

= DRT.K, if TAP.K $<$ 0.0 (46,A)

Where TRO is Trial Rate Of transfer, T-2/months

This trial rate will be the maximum if TAP is greater than zero, which indicates that at least some vessels will be chartered on voyage, so that all owned vessels should also be operating. If TAP is less than zero, the rate will be that desired to adjust the numbers of tankers in operation. This trial rate is next checked against the limits it may reach so as not to cause negative quantities of tankers.

ULR.K = ITO.K/DT (47,A)

LLR.K = - TOC.K/DT (48,A)

STR.K = ULR.K, if TRO.K $>$ ULR.K

= TRO.K, if TRO.K $<$ ULR.K (49,A)

ROT.KL = STR.K, if STR.K $>$ LLR.K

= LLR.K, if STR.K $<$ LLR.K (50,R) where ULR is Upper Limit on Rate, T-2/months

LLR is Lower Limit on Rate, T-2/months

STR is Second Trial Rate, T-2/months

ROT is Rate of Oil company vessel Transfer, T-2/months

The only parameter in this sector is TNOO, which is set equal to 0.5 months.

D. Independent Owners

This sector incorporates three basic functions of the independent owners. It keeps account of the independently owned vessels, it generates their scrappage rates, and generates their ordering of new vessels. See Figure VIII for the flow diagram for this sector.

OTI.K = OTI.J + (DT) (TDI.JK - RSI.JK) (51,L)

ITI.K = ITI.J + (DT) (TDI.JK + RVI.JK + RTI.JK - RVO.JK - RTO.JK - RSI.JK) (52,L)

Where OTI is Owned Tankers of Independents, T-2s

TDI is Tanker Delivery rate to Independents, T-2/mon.

RSI is Rate of Scrappage, Independents, T-2/mon.

ITI is Idle Tankers, Independents, T-2s

RVI is Rate of Voyage Charters going Idle, T-2s/mon.

RTI is Rate of Time charters going Idle, T-2/mon.

RVO is Rate of Voyage charters going into Operation, T-2/mon.

RTO is Rate of Time charters going into Operation, T-2/mon.

These two equations merely keep track of the owned and idle vessels respectively.

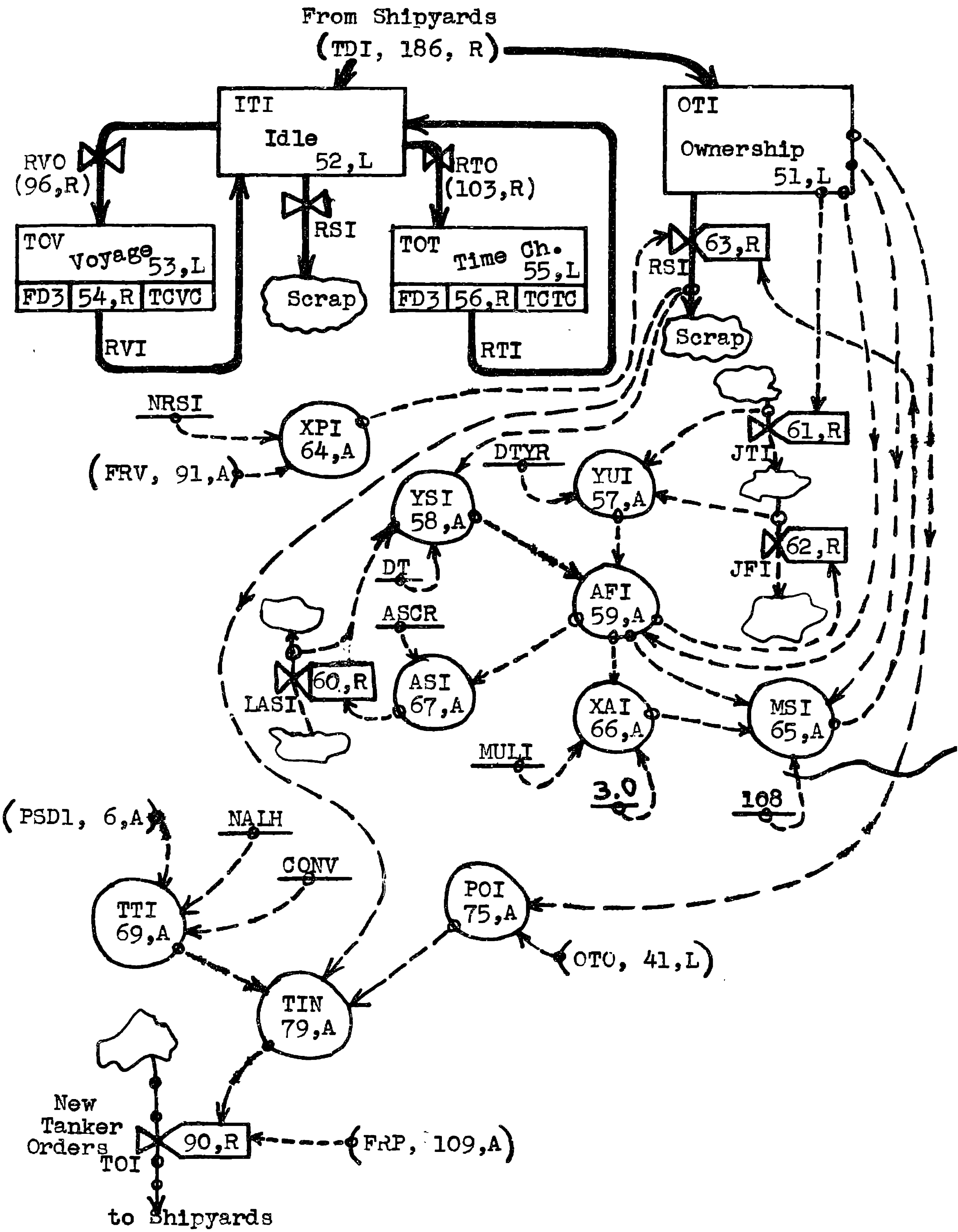
TOV.K = TOV.J + (DT) (RVO.JK - RVI.JK) (53,L)

RVI.KL = DELAY 3 (RVO.JK,TCVC) (54,R) where TOV is Tankers On Voyage charter, T-2s

TCVC is Time, average, on Charter for Voyage Charters, mon. These equations account for vessels on voyage charter. A third order exponential delay is used to approximate the aggregated flow of tankers.

Figure VIII

Independent Owners Flow Diagram



Thus, on the average each tanker remains on charter for TCVC months.

TOT.K = TOT.J + (DT) (RTO.JK - RTI.JK) (55,L)

RTI.KL = DELAY 3 (RTO.JK,TCTC) (56,R) where TOT is Tankers On Time Charter, T-2s

TCTC is Time, average, on Charter for Time Charters, mon.

These equations account for vessels on time charter.

The rate at which vessels will be scrapped depends basically upon the costs of maintaining and operating the vessel compared to expected freight rates. If the freight rates are low and there are many idle tankers, there will be greater incentive to scrap old vessels whose expected life is short. Newer vessels, of course, will not be scrapped since there are expectations that eventually the freight rate will improve, besides which the operating costs are probably lower. Thus, in formulating the decision rule for scrappage rate, we must take into consideration the age distribution of the vessels involved.

YUI.K = (OTI.K) (AFI.K + DTYR) (57,A)

YSI.K = (RSI.JK) (DT) (ASI.K) (58,A)

AFI.K = (YUI.K - YSI.K) /OTI.K (59,A) where YUI is T-2 Years of Unscrapped vessels, independents, T-2-years

YSI is T-2 Years of Scrapped vessels, Independents, T-2-years

DTYR is solution time interval, years

AFI is average Age of Fleet, Independents, years

ASI is average Age of Scrappage, Independents, years

These equations keep a running tabulation of the average age of the independently owned fleet. In the above equations, we must actually use not the present time step's values of AFI, OTI, and ASI, but the previous time step's values. (This also avoids simultaneous equations.) Therefore, we set up three artificial rates to be able to use such previous time step values.

LASI.KL = ASI.K (60,R)

JTI.KL = OTI.K (61,R)

JFI.KL = AFI.K (62,R)

These rates (their JK value which therefore corresponds to the J value of the variables) are then used in equations (57), (58), and (59). It should also be noted that as new vessels are added to the fleet, their average age for the first time step is zero, and therefore, does not enter the above computation.

The rate of scrappage will be considered as a function of the freight rate. Scrappage, of course, decreases as the freight rate rises. It will reach some theoretically maximum value at an impossible freight rate of zero. We shall say the rate of scrappage falls exponentially with increasing freight rate and has a maximum value based upon an assumed triangular age distribution of the fleet and certain policy considerations.

RSI.KL = (MSI.K) e (XPI.K) (63,R)

XPI.K = (FRV.K) logn (NRSI) (64,R) where RSI is Rate of Scrappage, independents, T-2/mon.

XPI is eXponential Power for scrappage rate, In dependents

FRV is Freight Rate index, Voyage

NRSI is Normal Rate of Scrappage, Independents, as fraction of maximum rate

MSI is Maximum rate of Scrappage, Independents, T-2/mon.

Thus, when the freight rate index is equal to one, which corresponds to normal conditions (steady state), the rate of scrappage will be a certain percentage (NRSI) of the maximum rate. This percentage is determined by policy considerations. The maximum rate may be derived from a triangular distribution to yield:

MSI.K = (OTI.K) $(XAI.K)^2$ $/(AFI.K)^2$ (108) (65,A)

XAI.K = (3) (AFI.K) - MULI (66,A) where XAI is eXcess Age in fleet, Independents, years

MULI is Minimlim age Limit on scrappage, Independents, years. This maximum rate is that which, based on a triangular age distribution, would scrap all vessels whose age exceeded MULI years within a year. The value of MULI is also based on policy considerations. The only variable that remains to be defined is ASI, the average age of scrappage. This, of course, depends on how much scrapping is instituted, in addition to the age distribution of the fleet. However, we shall only relate it to the later factor at present.

ASI.K = (AFI.K) (ASCR) (67,A) where ASCR is Age of SCRappage as multiple of average age of fleet

It is not felt that the above simplification will have a major effect on over-all system behavior.

In deciding upon the new vessel ordering, the predicted freight rate has a direct influence upon the independent owners. They will only order new tankers when they foresee favorable conditions. Unfortunately, as it later turns out, their foresight is not very good and influenced greatly by present circumstances. The following decision rule formulation is only a first approximation that is extremely rough. As is later shown, extensive revision was required.

POI.K = OTI.K/ (OTI.K + OTO.K) (75,A)

TTI.K = (PSD1.K) (NALH) (CONV) (69,A)

TIN.K = RSI.JK + (TTI.K) (POI.K) (79,A) where POI is Percentage of total vessels Owned by Independents

TTI is predicted rate of Tonnage Increase, T-2/mon.

TIN is Tankers to be ordered by Independents, with Normal freight rate, T-2/mon.

This normal ordering rate just makes up for scrapped vessels and the predicted increase, assuming that their share of the market remains unchanged. The influence of freight rates now enters.

TOI.KL = (TIN.K) $(FRP.K)^{\frac{1}{2}}$ (90,R) where TOI is Tanker Ordering rate, Independents, T-2/mon.

FRP is Freight Rate index, Predicted

Thus, the normal ordering rate is modified according to the predicted freight rate to give the actual ordering rate. This decision rule does not include any provision for cancellation of orders which, in fact, occurs. Nor does it allow for the independent owners attempting to increase their share of the market.

The parameters of this sector, as used in the original model, are as follows:

TCVC = 1.5 months

TCTC = 54 months

MULI = 23 years

NRSI = 36/49

ASCR = 2.5

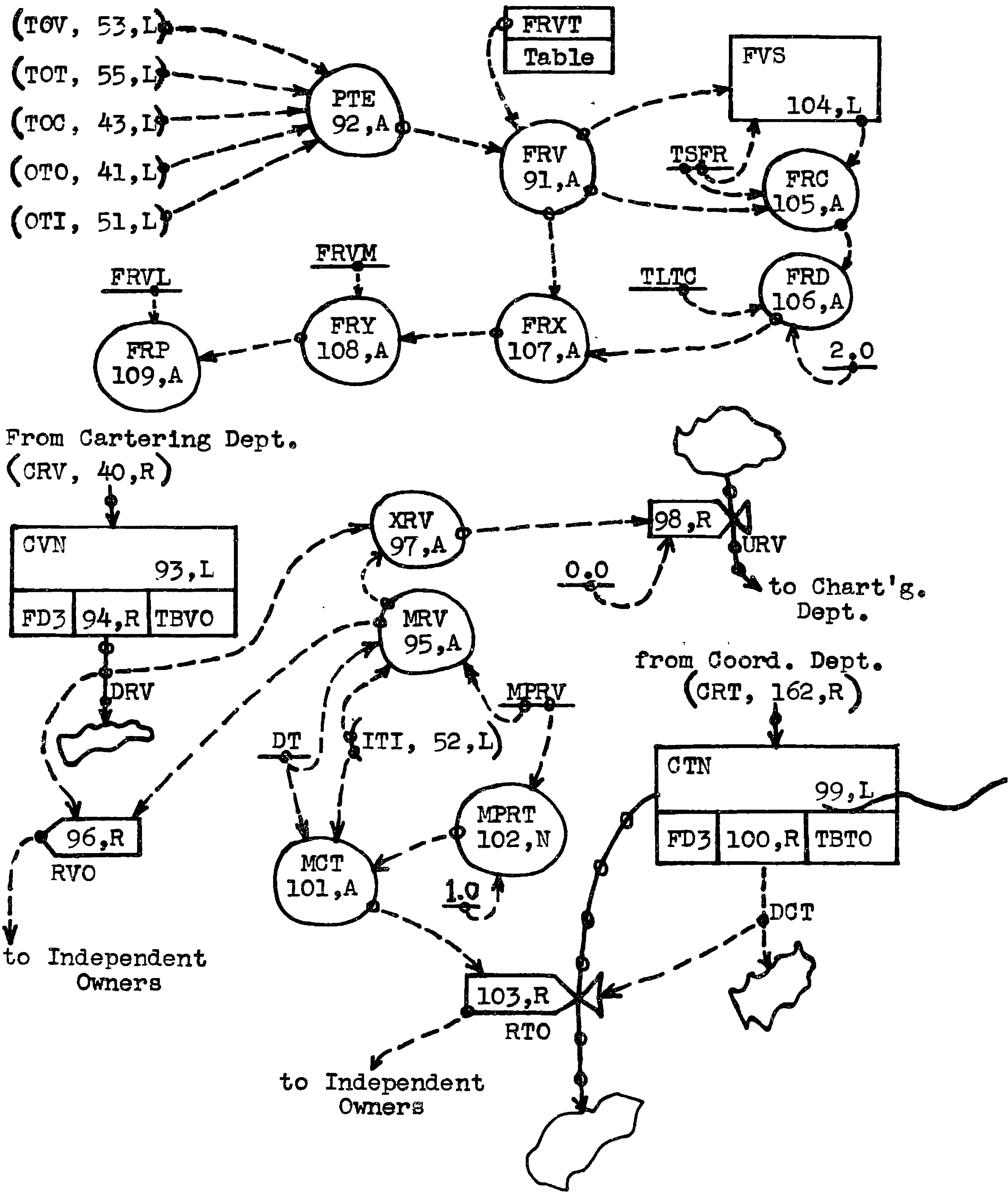
E. Tankship Brokers

The main function of the tankship brokers sector is to receive and hold the charter agreements, and in effect to determine the rate at which vessels will enter charter service. The brokers also determine the market freight rate and its predicted value. See Figure IX for the flow diagram of this sector.

The voyage freight rate is determined simply through a static

Figure IX

Tankship Brokers Flow Diagram



supply schedule. This schedule, in the form of a table of values, gives a freight rate for any percentage of fleet employment.

FRV.K = TABLE (FRVT,PTE.K) (91,A)

PTE.K = (TOV.K + TOT.K + TOC.K) /(OTI.K + OTC.K) (92,A) where

FRV is Freight Rate index, Voyage

FRVT is Tabular values of FRV

PTE is Percentage of Tankers Employed

Such a freight rate formulation assumes unchanging costs of operation over time. It further assumes a rigid market reaction to any given tanker employment ratio.

CVN.K = CVN.J + (DT) (CRV.JK - DRV.JK) (93,L)

DRV.KL = DELAY 3 (CRV.JK,TBVO) (94,R) where CVN is Chartered tankers, Voyage, Not yet in operation, T-2s

CRV is Chartering Rate, Voyage, actual, T-2/mon.

DRV is Desired Rate of Voyage charters going into operation, T-2/mon.

TBVO is Time, average, Before Voyage charters go into Operation, mon.

The first equation above represents the charters that have been signed, but are not yet in operation. The second equation is the desired rate of such charters going into operation. This rate is limited by the number of idle vessels.

MRV.K = (ITI.K) (MPRV) /DT (95,A)

RVO.KL = DRV.JK, if MRV.K $>$ DRV.JK

= MRV.K, if MRV.K $<$ DRV.JK (96,R) where MRV is Maximum value of RVO, T-2/mon.

MPRV = Maximum PeRcentage of idle vessels going into Voyage charter

RVO is Rate of Voyage charters going into Operation, T-2/mon.

If the desired rate is greater than the maximum rate, this means that not all of the charters will be instituted. Those that are not are sent back to the chartering department.

$$XRV.K = DRV.JK - MRV.K \quad (97,A)$$

$$URV.KL = XRV, \text{ if } XRV.K > 0.0$$

$$= 0.0, \text{ if } XRV.K < 0.0 \quad (98,R)$$ where XRV is difference between desired and maximum rates, T-2/mon.

URV is Unfilled chartering Rate, Voyage

The rate URV goes back to the chartering department if XRV is positive (it is otherwise zero).

A similar situation exists for time charters, with the exception that any unfilled demand is discarded and not held for future fulfillment.

$$CTN.K = CTN.J + (DT)(CRT.JK - RTO.JK) \quad (99,L)$$

$$DCT.KL = DELAY\ 3\ (CRT.JK, TBTO) \quad (100,R)$$

$$MCT.K = (ITI.K)(MPRT)/DT \quad (101,A)$$

$$MPRT = 1.0 - MPRV \quad (102,N)$$

$$RTO.KL = DCT.JK, \text{ if } MCT.K > DCT.JK$$

$$= MCT.K, \text{ if } MCT.K < DCT.JK \quad (103,R)$$ where CTN is Chartered tankers, Time, Not yet in operation, T-2s

CRT is Chartering Rate, Time, actual, T-2/mon.

RTO is Rate of Time charters going into Operation, T-2/mon.

DCT is Desired rate of Time charters going into operation, T-2/mon.

TBTO is Time, average, Before Time charters go into Operation, mon.

MCT is Maximum value of RTO, T-2/mon.

MPRT is Maximum PeRcentage of idle vessels going into Time charter

The tankship brokers also generate a predicted freight rate. As in the case of projections made earlier, the smoothed, or average, freight rate changes are used to forecast changes in the freight rate.

$$\mathrm{FVS.K} = \mathrm{FVS.J} + (\mathrm{DT}/\mathrm{TSFR})\,(\mathrm{FRV.J} - \mathrm{FVS.J}) \qquad (104,\mathrm{L})$$

$$\mathrm{FRC.K} = (\mathrm{FRV.K} - \mathrm{FVS.K})\,/\mathrm{TSFR} \qquad (105,\mathrm{A})$$

where FVS is Freight rate index, Voyage, Smoothed

FRC is Freight rate index rate of Change, mon.

TSFR is Time period for Smoothing FRV, mon.

The variable FRC is the rate of change of the smoothed freight rate and will be used to project the actual freight rate into the future. In addition, upper and lower limits are set on the predicted freight rate in accord with the limits of the freight rate schedule.

$$\mathrm{FRD.K} = (\mathrm{TLTC})\,(\mathrm{FRC.K})\,/2 \qquad (106,\mathrm{A})$$

$$\mathrm{FRX.K} = \mathrm{FRV.K} + \mathrm{FRD.K} \qquad (107,\mathrm{A})$$

$$\mathrm{FRY.K} = \begin{cases} \mathrm{FRX.K}, & \text{if } \mathrm{FRVM} > \mathrm{FRX.K} \\ \mathrm{FRVM}, & \text{if } \mathrm{FRVM} < \mathrm{FRX.K} \end{cases} \qquad (108,\mathrm{A})$$

$$\mathrm{FRP.K} = \begin{cases} \mathrm{FRY.K}, & \text{if } \mathrm{FRY.K} > \mathrm{FRVL} \\ \mathrm{FRVL}, & \text{if } \mathrm{FRY.K} < \mathrm{FRVL} \end{cases} \qquad (109,\mathrm{A})$$

where FRD is average Difference in future and present value of FRV

FRX is average future value of FRV

FRY is second trial value of FRP

FRP is Freight Rate index, Predicted

TLTC is Time period for Long Term Considerations, mon.

FRVM is Maximum value of FRV

FRVL is minimum value of FRV

This predicted freight rate will be extremely sensitive to the actual freight rate because the value of TSFR is usually quite small. That is, the average freight rate is not averaged very far back into the past in trying to look at trends.

The parameters of this sector, as used in the original model, are as follows:

FRVT = see Plot I

TBVO - 2 months

TBTO = 20 months

MPRV = 0.93

TSFR = 3 months

TLTC = 48 months

FRVL = 0.50

FRVM = 3.50

As can be seen from Plot I, the supply schedule is extremely flat below normal tanker utilization (PTE = .96), and extremely steep above this point. This is typical of a very short run (static) supply situation.

F. <u>Coordination Department</u>

The coordination department of the oil company marine divisions executes the major policy decisions for their segment of the industry. It is here that rates of scrappage, new tanker orders, and time charters are generated based upon long-term policy considerations. See Figure X (both Part one and Two) for the flow diagram of this sector.

The rate of scrappage is generated in the same manner that the independent owners did so. The difference lies in choice of parameters which determine the general level of such scrappage. The equations will, therefore, be presented without further explanation.

YUO.K = (JTO.JK) (JFO.JK + DTYR) (110,A)

DTYR = DT/12 (111,A)

YSO.K = (RSO.JK) (DT) (LASO.JK) (112,A)

AFO.K = (YUO.K - YSO.K) /OTO.K (113,A)

RSO.KL = (MSO.K) e $^{(XPO.K)}$ (114,R)

PLOT I

STATIC SUPPLY SCHEDULE

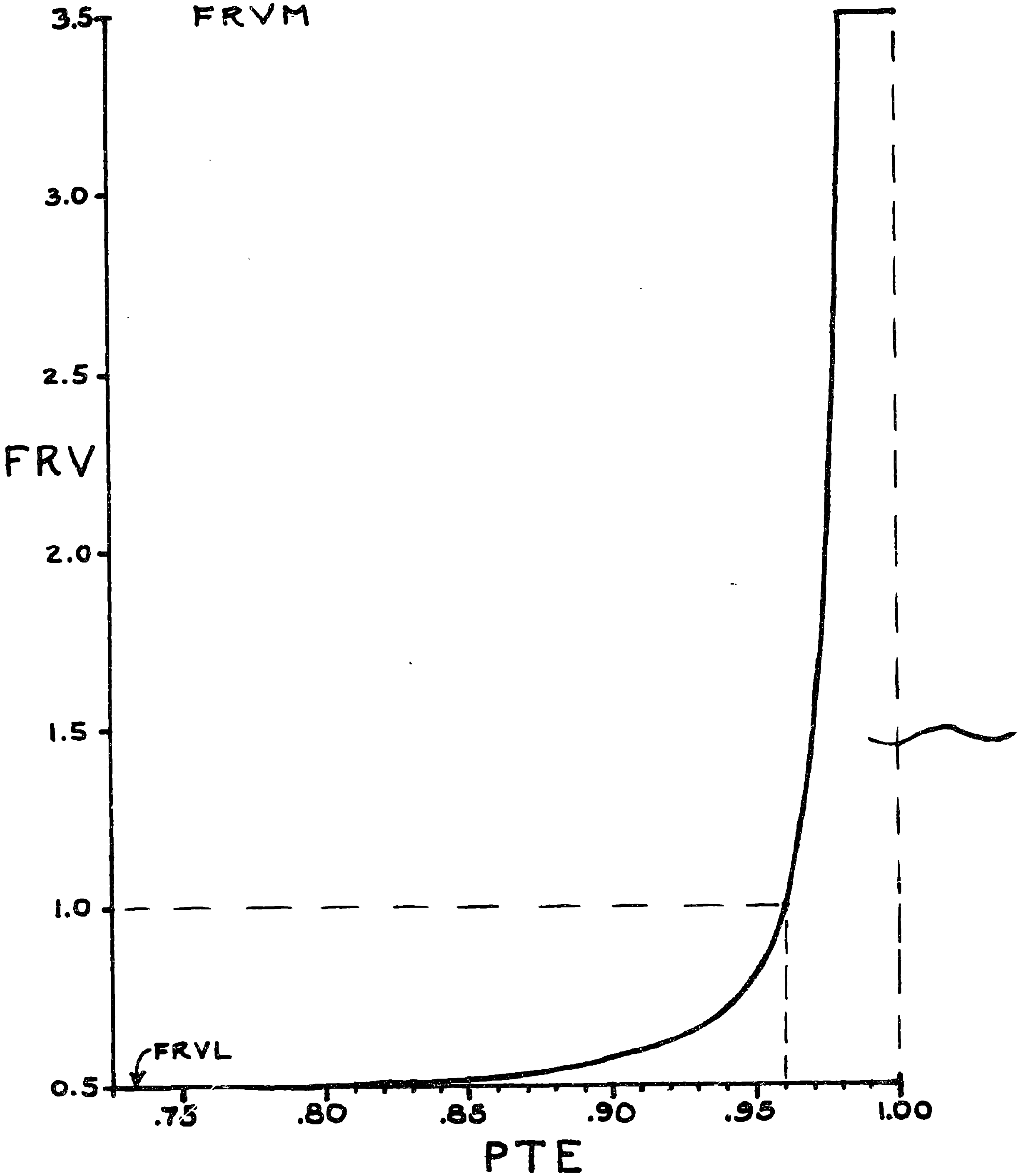
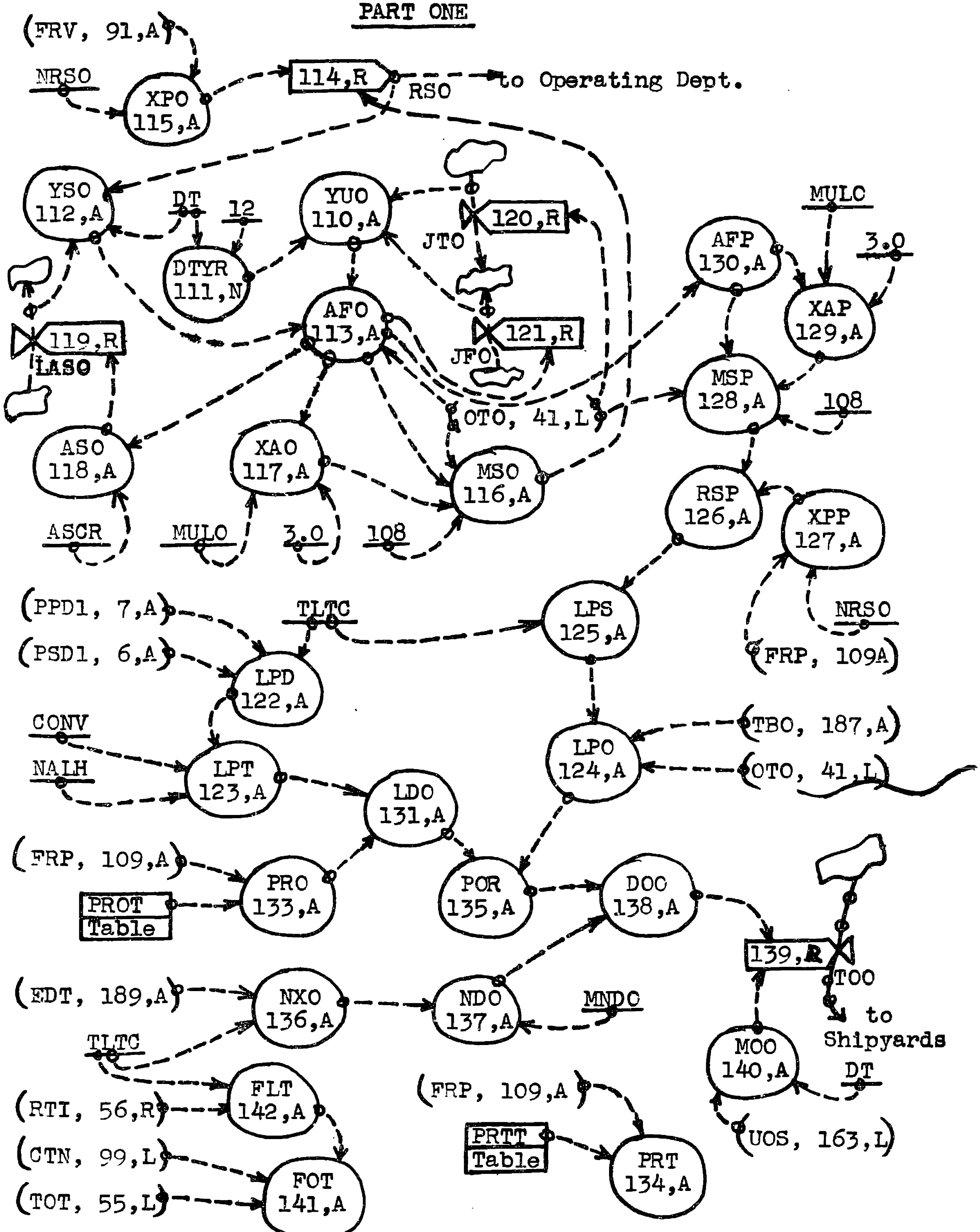


Figure X

Coordination Department Flow Diagram

PART ONE

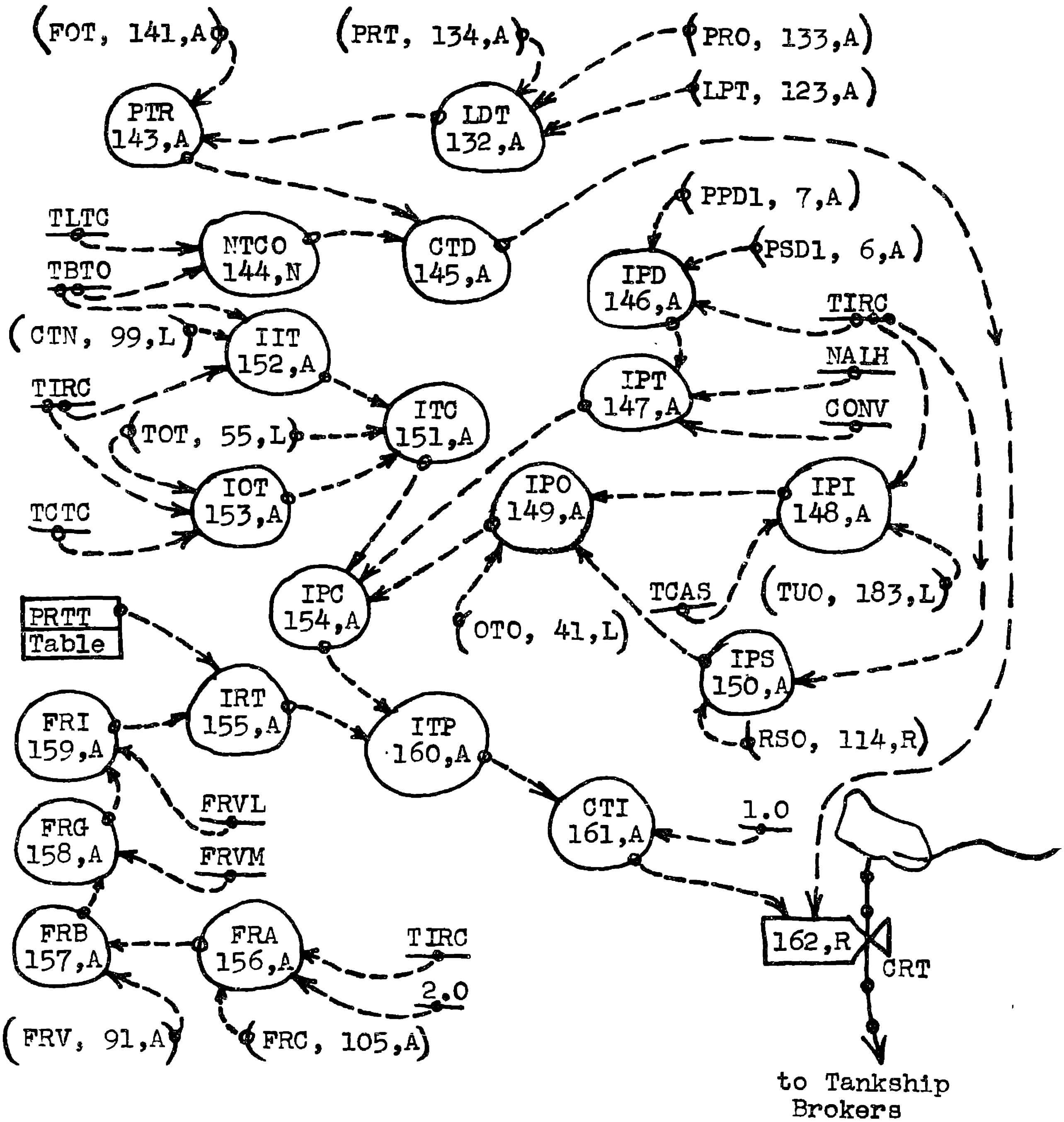


TO PART TWO ← NEXT PAGE

Figure X (cont'd.)

Coordination Department Flow Diagram

Part TWO



XPO.K = (FRV.K) logn (NRSO) (115,A)

MSO.K = (OTO.K) $(XAO.K)^2/(AFO.K)^2$ (108) (116,A)

XAO.K = (3) (AFO.K - MULO (117,A)

ASO.K = (AFO.K) (ASCR) (118,A)

LASO.KL = ASO.K (119,R)

JTO.KL = OTO.K (120,R)

JFO.KL = AFO.K (121,R) where YUO is T-2 Years of Unscrapped vessels, Oil companies, T-2,years

YSO is T-2 Years of Scrapped vessels, Oil companies, T-2, years

AFO is average Age of Fleet, Oil companies, years

RSO is Rate of Scrappage, Oil companies, T-2/months

XPO is eXponential Power for scrappage rate, Oil companies

MSO is Maximum rate of Scrappage, Oil companies, T-2/months

XAO is eXcess Age in fleet, Oil companies, years

ASO is average Age of Scrappage, Oil companies, years

MULO is MinimUm age Limit on scrappage, Oil companies, years

NRSO is Normal Rate of Scrappage, Oil companies, as fraction of maximum rate

In trying to decide upon an ordering rate for new vessels, the oil company planners must look far into the future and estimate supply and demand. This is a difficult thing to do accurately from the outset, while one's method may make it even more difficult to reach reliable results.

LPD.K = PPD1.K + (PSD1.K) (TLTC) (122,A)

LPT.K = (LPD.K) (NALH) (CONV) (123,A) where LPD is Long term Projected Demand for oil, bbls/day

LPT is Long term Projected demand for Tankers, T-2s

TLTC is Time period for Long Term Considerations, months

These equations predict the demand for TLTC months into the future. The supply of owned vessels is next estimated for the same point in time.

LPO.K = OTOK + TBO.K - LPS.K (124,A) where LPO.K is Long term Projected tanker Ownership, T-2s

TBO is Tanker Backlog at shipyards of Oil companies, T-2s

OTO is Owned Tankers of Oil companies, T-2s

LPS is Long term Projected Scrappage, T-2s

LPS.K = (RSP.K) (TLTC) (125,A)

RSP.K = (MSP.K) e $^{(XPP.K)}$ (126,A)

XPP.K = (FRP.K) logn (NRSO) (127,A)

MSP.K = (OTO.K) $(XAP.K)^2/(AFP.K)^2$ (108) (128,A)

XAP.K = (3) (AFP.K) - MULO (129,A)

AFP.K = AFO.K (130,A) where RSP is Rate of Scrappage, Projected, T-2/months

XPP is eXponential Power, Projected

MSP is Maximum rate of Scrappage, Projected, T-2/months

XAP is eXcess Age of fleet, Projected, years

AFP is average Age of Fleet, Projected, years

The scrappage is projected on the basis of the predicted average freight rate, FRP, and the projected average age of fleet. However, the latter has been set equal to its present value as a first approximation. This should not be too critical at all in the over-all picture.

At this point an important consideration is made. On the basis of the predicted freight rate, a desired market distribution (as between owned vessels, time charters, and voyage charters) is decided upon. This, in conjunction with predicted demand, will set up the goals for new construction orders, and time chartering as well.

LDO.K = (LPT.K) (PRO.K) (131,A)

LDT.K = (LPT.K) (PRT.K - PRO.K) (132,A)

PRO.K = TABLE (PROT, FRP.K) (133,A)

PRT.K = TABLE (PRTT, FRP.K) (134,A) where LDO is Long term Desired Ownership, T-2s

LDT is Long term Desired Time charters, T-2s

PRO is Percentage of Requirements to be met by Owned vessels

PROT is Tabular values of PRO

PRT is Percentage of Requirements to be met by Time charters plus owned ships

PRTT is Tabular values of PRT

We can now compare our desired ownership to our projected to aid in determining our ordering rate.

POR.K = LDO.K - LPO.K (135,A) where POR is Predicted additional Ownership Requirements, T-2s.

The available time in which to negotiate for these vessels will determine how fast these orders should be placed. Of course, there is a minimum negotiation time, as well as a minimum order rate. That is, orders may be cancelled only up to a certain point, beyond which it is too costly. We have, therefore, broken up the backlog at the shipyard into two parts. The first part represents small amount of work on the order and it can be cancelled from this part. However, once it goes into the next phase, it can no longer be cancelled. The first part is labelled as "unstarted orders" while the second "tankers under construction", to clearly differentiate between them. We have, therefore:

NXO.K = TLTC - EDT.K (136,A)

$$
NDO.K = \begin{cases} NXO.K, & \text{if } NXO.K > MNDO \\ MNDO, & \text{if } NXO.K < MNDO \end{cases} \quad (137,A)
$$

DOO.K = POR.K/NDO.K (138,A)

TOO.KL = DOO.K, if DOO.K $>$ MOO.K

= MOO.K, if DOO.K $<$ MOO.K (139,R)

MOO.K = UOS.K/EDT (140,A) where NXO is Negotiation time available to Oil companies, months

EDT is Estimated Delivery Time, from shipyards, months

NDO is Negotiation time used by Oil companies, months

MNDO is Minimum value of NDO, months

DOO is Desired Order rate, Oil companies, T-2/months

TOO is Tanker Order rate, Oil companies, T-2/months

MOO is Minimum Order rate, Oil companies, T-2/months

UOS is Unstarted orders, Oil companies, at Shipyards, T-2s

It should be noticed that this decision rule includes definite provision for order cancellation, and consideration of the over-all market position.

The time chartering rate is determined in a very similar manner to new vessel ordering. However, the result is modified to meet conditions in the intermediate run, that longer than the short run, but not hardly as long as the long run. Such modifications have been thought to cause what are called "shortage scares". That is, an oil company foreseeing a tight market, say in six months to a year, will start charting heavily in the time market field so that such vessels will remain in the oil company's service through the tight conditions. When this is carried too far by too many companies, it depletes the voyage charter fleet and aggravates conditions prematurely. At any rate, we can say:

FOT.K = CTN.K + TOT.K - FLT.K (141,A) where FOT is Future number of vessels On Time charter, T-2s

FLT is Future amount of vessels Leaving Time charter, T-2s

In actual practice, the oil companies would know the figure for FOT, the future number of vessels on time charter, (assuming no more charters are placed) with a high degree of accuracy. This number would be the sum of those vessels now on time charter that would remain so, and those vessels for which at present charters have been signed, but have not yet gone into operation, that would also be in operation at the point in the future (this, of course, assumes all charters will be honored). Since in this model both the levels of vessels on time charter and those signed up, but not yet in operation, have third order exponentially delayed rates of flow, it would here too be possible to predict this future value with a high degree of precision. The general method, using differential equations up to the sixth order, is outlined in Appendix B. For the model, however, equation (141) was used.

FLT.K = (TLTC) (RTI.JK) (142,A) where RTI is Rate of Time charters going Idle, T-2/months

A desired time chartering rate is next developed.

PTR.K = LDT.K - FOT.K (143,A)

NTCO = TLTC - TBTO (144,N)

CTD.K = PTR.K/NTCO (145,A) where PTR is Predicted additional time charters Required, T-2s

NTCO is Negotiation time available for Time Charters, Oil companies, months

CTD is Chartering rate, Time, Desired, T-2/months

It is here that the intermediate run considerations enter the picture. First, the demand is predicted, then the supply of owned plus time chartered vessels is predicted, and the ratio of the latter to the former compared to the desired ratio, based this time on long term considerations.

IPD.K = PPD1.K + (PSD1.K) (TIRC) (146,A)

IPT.K = (IPD.K) (NALH) (CONV) (147,A)

IPI.K = (TIRC) (TUO.K)/TCAS (148,A)

IPO.K = OTO.K + IPI.K - IPS.K (149,A)

IPS.K = (RSO.JK) (TIRC) (150,A)

ITC.K = TOT.K + IIT.K - IOT.K (151,A)

IIT.K = (TIRC) (CTN.K) /TBTO (152,A)

IOT.K = (TIRC) (TOT.K)/TCTC (153,A)

IPC.K = (IPO.K + ITC.K)/IPT.K (154,A) where IPD is Intermediate Projected Demand for oil, bbls/day

IPT is Intermediate Projected demand for Tankers, T-2s

IPI is Intermediate Projected Increase in owned vessels, T2-s

IPO is Intermediate Projected Ownership, T-2s

IPS is Intermediate Projected Scrappage, T-2s

ITC is Intermediate projected Time Charters, T-2s

IIT is Intermediate Increase in Time charters, T-2s

IOT is Intermediate decrease in Time charters, T-2s

IPC is Intermediate Percentage of demand Covered by either owned or time charter ships

TIRC is Time period for InteRmediate Considerations, months

This last percentage (IPC) is compared to that obtained by referring an intermediate predicted freight rate to PRTT.

IRT.K = TABLE (PRTT,FRI.K) (155,A)

FRA.K = (TIRC) (FRC.K)/2 (156,A)

FRB.K = FRV.K + FRA.K (157,A)

FRG.K = FRB.K, if FRVM $>$ FRB.K

= FRVM, if FRVM $<$ FRB.K (158,A)

FRI.K = FRG.K, if FRG.K $>$ FRVL

= FRVL, if FRG.K $<$ FRVL (159,A) Where IRT is Intermediate desired Ratio of coverage to Total demand

FRI is Freight Rate index, predicted, Intermediate

(Note: FRA, FRB, and FRG are similar to FRD, FRX, and FRY) The two ratios form a factor which influences the desired chartering rate.

ITP.K = IRT.K/IPC.K (160,A)

CTI.K = (1.0) $(\text{ITP.K})^{\frac{1}{2}}$ (161,A)

CRT.K = (CTD.K) (CTI.K) (162,R) where ITP is Intermediate ratio of desired to Projected coverage

CRT is Chartering Rate, Time, coverage, actual, T-2/months

The parameters of this sector, as used in the original model, are as follows:

PRTT, PROT, see Plot II

TLTC = 48 months

MULO = 18 years

NRSO - 4/5

TIRC = 9 months

MNDO = 4 months

G. Shipyard Sector

The shipyard sector serves basically to convert tanker orders into tanker deliveries. In some respects it is modeled after the factory sector presented in reference (15). See Figure XI for the flow diagram for this sector.

Orders, as they are received, go into the first phase of backlog (from which they can be cancelled).

UOS.K = UOS.J + (DT) (TOO.JK - TCO.JK) (163,L)

PLOT II

MARKET DISTRIBUTION POLICY
(COORDINATION DEPT.)

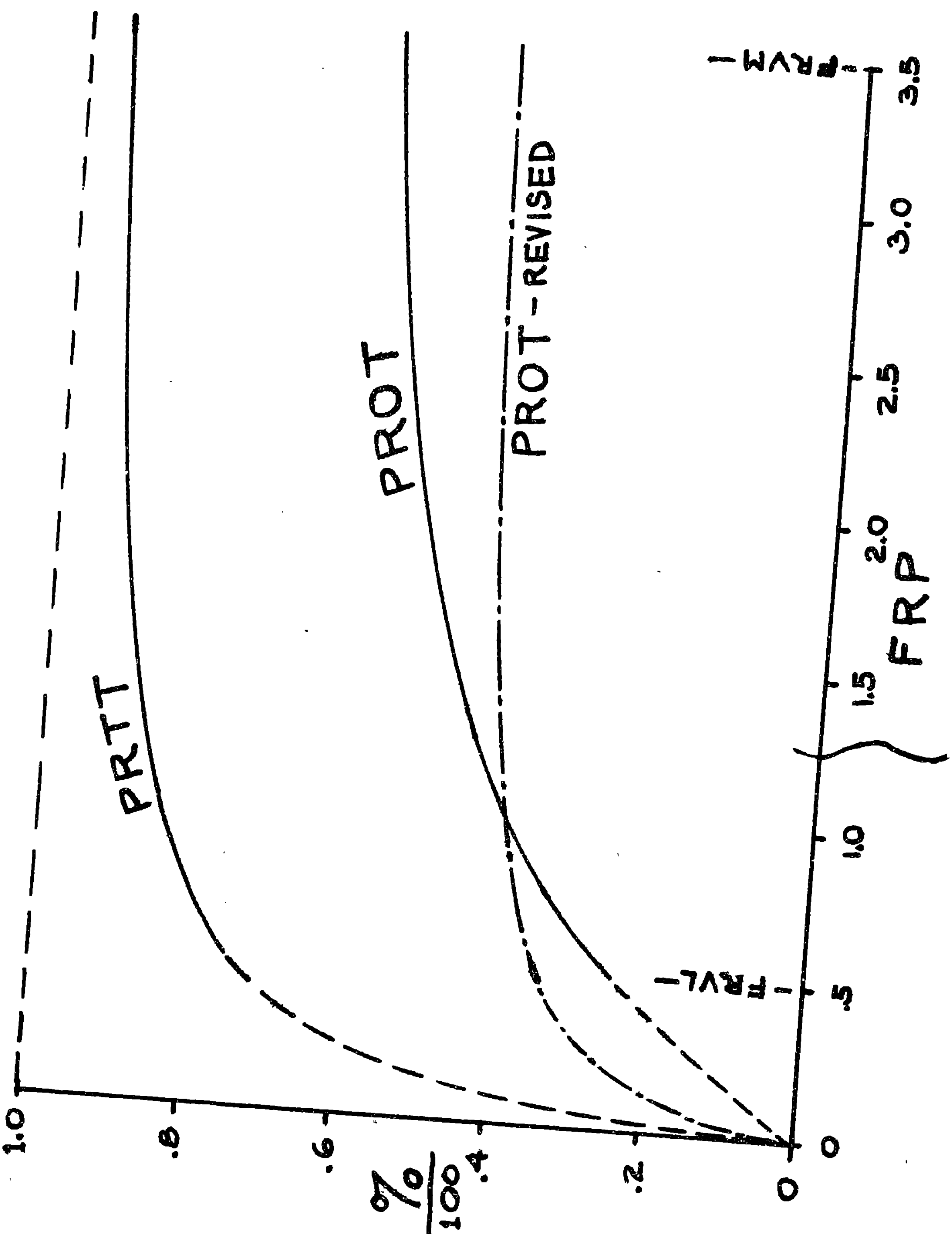
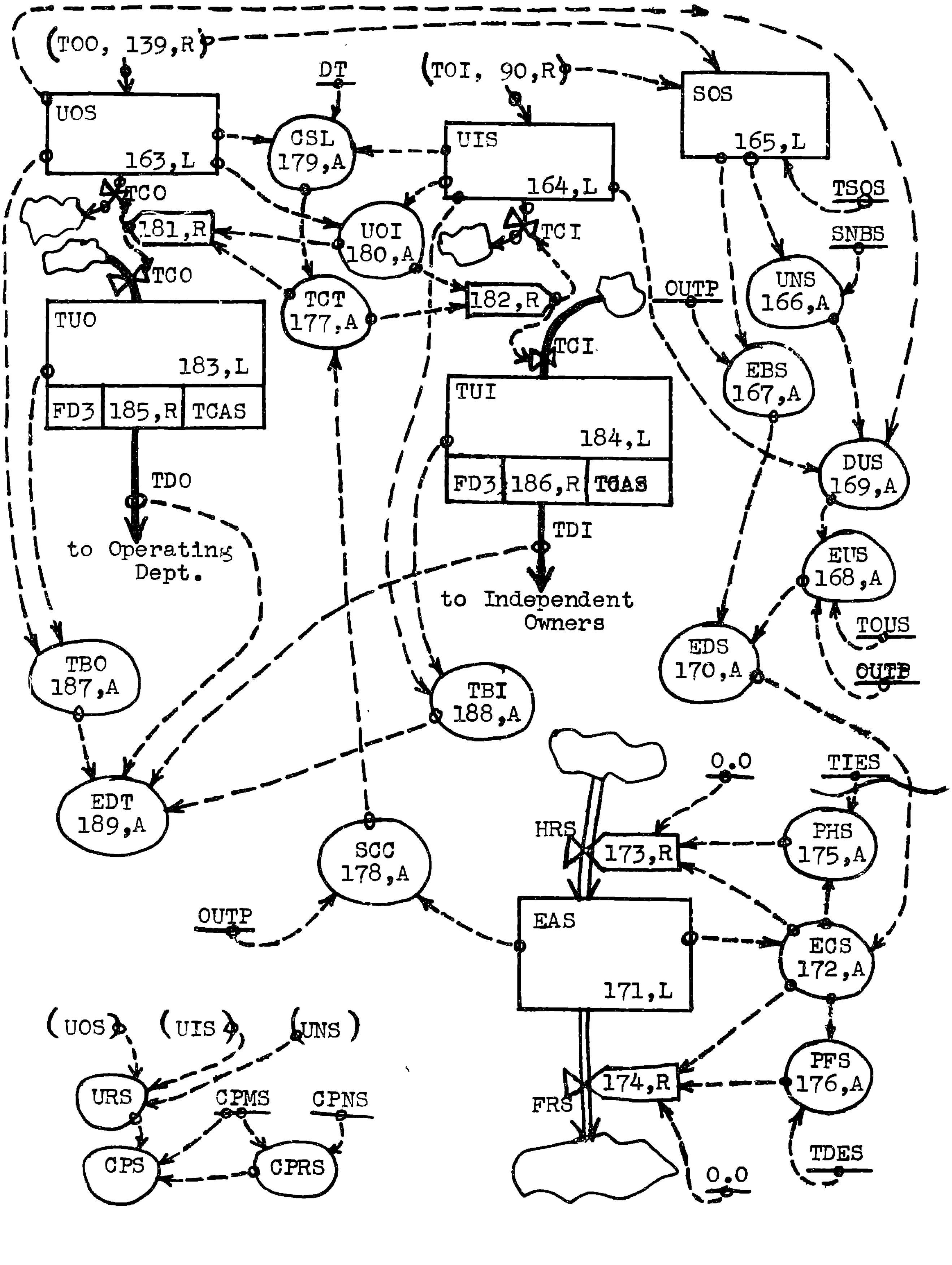


Figure XI

Shipyard Sector Flow Diagram



UIS.K = UIS.J + (OT) (TOI.JK - TCI.JK) (164,L) when UOS is Unstarted Orders, Oil companies, at Shipyards, T-2s

UIS is Unstarted orders, Independents, at Shipyards, T-2s

TCO is Tanker Construction start rate, Oil companies, T-2/months

TCI is Tanker Construction start rate, Independents, T-2/months

The order rates coming in are then smoothed to get a long run average of the level of business activity. This is used to determine a normal backlog and a base employment level.

SOS.K = SOS.J + (DT/TSOS) (TOO.JK + TOI.JK - SOS.J) (165,L)

UNS.K = (SOS.K) (SNBS) (166,A)

EBS.K = SOS.K/OUTP (167,A) where SOS is Smoothed Order rate, at Shipyards, T-2/months

TSOS is Time period for Smoothing Order rate, at Shipyards, months

UNS is Unstarted order backlog, Normal, at Shipyards, T-2s

SNBS is Size of Normal Backlog at Shipyard (in terms of months of averaged order rate), mon.

EBS is Employment, desired for normal Business level, ~~months~~ men

OUTP is productivity OUTPut, T-2/men-months

The rate at which construction activity is started, that is, the rate at which orders become vessels under construction, is based on the employment level at the shipyards. This in turn is based upon the above EBS, or base level, plus an adjustment to correct the size of backlog if it is not at the normal level.

EUS.K = DUS.K/ (OUTP) (TOUS) (168,A)

DUS.K = UIS.K + UOS.K - UNS.K (169,A)

EDS.K = EBS.K + EUS.K (170,A) where EUS is Employment, desired to correct size of Unstarted backlog, at Shipyards, men

DUS is Difference between actual and normal Unstarted backlog, at

Shipyards, T-2s

TOUS is Time period Over which it is desired to correct Unstarted backlog, at Shipyards, months

EDS is Employment, Desired, total, at Shipyards, men

This desired employment level is instituted through the hiring and firing of employees. The difference between the desired and actual employment levels determines the hiring or firing rates. Thus, we have the following equations:

$$EAS.K = EAS.J + (DT)(HRS.JK - FRS.JK) \quad (171,L)$$

$$ECS.K = EDS.K - EAS.K \quad (172,A)$$

$$HRS.KL = PHS.K, \text{ if } ECS.K > 0.0$$
$$= 0.0, \text{ if } ECS.K < 0.0 \quad (173,R)$$

$$FRS.KL = PFS.K, \text{ if } - ECS.K > 0.0$$
$$= 0.0, \text{ if} -ECS.K < 0.0 \quad (174,R)$$

$$PHS.K = ECS.K/TIES \quad (175,A)$$

$PFS.K = - ECS.K/TDES \quad (176,A)$ where EAS is Employment Actual, at Shipyards, men

HRS is Hiring Rate, at Shipyards, men/months

FRS is Firing Rate, at Shipyards, men/months

ECS is Employment Change desired, at Shipyards, men

PHS is Possible Hiring rate, at Shipyards, men/months

PFS is Possible Firing rate, at Shipyards, men/mon.

TIES is Time on which it is desired to Increase Employment, at Shipyards, months

TDES is Time over which it is desired to Decrease Employment, at Shipyards, months

The actual employment level determines the shipyards' capability to start new construction. However, this is limited by the amount of unstarted backlog available to draw upon.

$TCT.K = CSL.K$, if $SCC.K > CSL.K$

$= SCC.K$, if $SCC.K < CSL.K$ (177,A)

$SCC.K = (EAS.K)(OUTP)$ (178,A)

$CSL.K = (UOS.K + UIS.K)/DT$ (179,A) where TCT is Total Construction sTart rate, T-2/months

SCC is Shipyard Construction Capability, T-2/months

CSL is Construction Start Limiting rate, T-2/months

This total construction start rate is then divided between oil companies and independents according to their relative backlog sizes.

$UOI.K = UOS.K/(UIS.K + UOS.K)$ (180,A)

$TCO.KL = (UOI.K)(TCT.K)$ (181,R)

$TCI.KL = (1.0 - UOI.K)(TCT.K)$ (182,R) where UOI is fraction of total Unstarted backlog ordered by oil companies

TCO is Tanker Construction start rate, Oil companies, T-2/months

TCI is Tanker Construction start rate, Independents, T-2/months

The construction period is treated as a third order delay with an average construction time.

$TUO.K = TUO.J + (DT)(TCO.JK - TDO.JK)$ (183,L)

$TUI.K = TUI.J + (DT)(TCI.JK - TDI.JK)$ (184,L)

$TDO.KL =$ DELAY 3 $(TCO.JK, TCAS)$ (185,R)

$TDI.KL =$ DELAY 3 $(TCI.JK, TCAS)$ (186,R) where TUO is Tankers Under construction for ~~Independents~~ Oil Companies, T-2s

TUI is Tankers Under construction for Independents, T-2s

TDO is Tanker Delivery rate to Oil companies, T-2/months

TDI is Tanker Delivery rate to Independents, T-2/months

TCAS is Time for vessel Construction, Average, at Shipyards, months

Additional quantities are now defined which are used in other sectors of the model.

TBO.K = UOS.K + TUO.K (187,A)

TBI.K = UIS.K + TUI.K (188,A) where TBO is Tanker Backlog at shipyards, Oil companies, T-2s

TBI is Tanker Backlog at shipyards, Independents, T-2s

EDT.K = (TBO.K + TBI.K)/(TDO.JK + TDI.JK) (189,A) where EDT is Estimated Delivery Time, from shipyards, months.

The above equations describe fully the shipyard sector as used in the model. However, merely as an indicator of shipyard activity, a shipyard construction price index was generated. The price is set up as a parabolic function of the ratio of unstarted backlog to normal unstarted backlog. There is a certain minimum price, regardless of how low the shipyards' backlog may be. As the backlog rises the price rises with the rate of change increasing.

URS.K = (UOS.K + UIS.K) /UNS.K

$CPS = CPMS + (URS.K)^2\ (CPRS)$

CPRS = CPNS - CPMS where URS is ratio of actual to normal unstarted backlog

CPS is Construction Price index, at Shipyards

CPMS is Minimum value of CPS

CPNS is Normal value of CPS

The parameters of this sector, as used in the original model, are as follows:

TSOS = 72 months

SNBS = 15 months

OUTP = 1/10,000 T-2/man-month

TOUS = 60 months

TIES = TDES = 4 months

TCAS = 18 months

CPMS = 0.80, CPNS = 1.00

The equations of the complete model (including a later revision) can be found in Appendix C. They are arranged according to the sectors presented here, and are written in the format required by DYNAMO IIa as specified in reference (5). They are, however, quite similar to their presentation in this chapter. To the left of each equation is its equation form number, and to the right are this author's equation serial numbers. Included in this tabulation are all the parameters required and the initial conditions used. The initial conditions represent a steady state condition where all levels and rates remain constant. Actual industry history seems to indicate a general continual growth of the industry, with a steady state never reached even in terms of steady growth. Though this initial condition is therefore not realistic, it serves as a convenient starting point from which to observe model response. After some time, the system should display its inherent characteristics regardless of initial conditions.

IV. RESULTS AND ANALYSIS

Before looking at some computer runs of the model, it is well to keep in mind some of the assumptions made, and omissions, in the model as formulated. Results must be looked at in the light of these before one can think of translating such results to real world conditions, for after all, the results are applicable to the real world only insofar as we trust the model is a representation of the real world.

After going through the model formulation it is obvious that much of it is a simplification, in varying degrees, of the real world considerations. Most of the decisions in reality are based on cost and profit analyses. These analyses are in turn based on expectations of the market to a considerable extent. The model, however, does not consider, for example, vessel operating costs versus expected revenue to decide on whether to scrap the vessel or not. Most of the model decision rules treat expectations directly, not through cost and revenue analyses. It is hoped that the decision rules, as formulated, include the major factors at work that lie at the true basis for making these decisions.

Costs are not considered in two other areas. In the decisions to order new vessels, no account is taken of the construction price charged by the shipyards. While this may have some actual effect on ordering, it is not felt to be of major proportions. That is, once it is decided that a new vessel is desired, it will be ordered regardless of cost. Since most vessels are ordered during good market conditions, a higher vessel cost will be easily accommodated. Also, in the voyage freight rate determination, it is assumed that the oil companies do not consider such costs, but merely charter vessels as their demand dictates regardless of freight rate. Certainly, at high freight rates the oil companies will take every effort to increase the efficiency of their own fleet so that their chartering is at a minimum rate.

The model does not include the time charter freight rate. This rate depends very closely on vessel operating costs and to a lesser degree on market conditions. It was not felt that inclusion of this rate would materially affect the system behavior, for this rate is system determined, not system determining.

There are many assumptions implicit in the formulation of the various parts of the model. These assumptions, however, are causing model behavior and we should gain some insight into them through analysis of model behavior. The first three computer runs with the original model used the following inputs: 1. 10% step in demand for oil, 2. ramp function, of 6% of initial conditions increase per year, in demand for oil, and 3, noise, randomly distributed, sampled once per month, within plus or minus 5% of initial conditions, in demand for oil (see Dynamo Run Nos. 883, 884, and 885. Copies of all runs are on file with the Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge).

The initial reaction of the system, in the first run, with the 10% step increase, is an obvious shortage of vessels. The freight rate almost immediately rises to its maximum limit and stays there for about 30 months, at which time enough new vessels have entered the industry so that the freight rate falls, and does so sharply. Once the freight rate drops, all tanker orders are cancelled by the oil companies but it is too late. The great number of vessels under construction, ordered during the high rate, keep coming out of the shipyards causing more and more surplus tonnage. Scrappage rates, which at first dropped off, rise with the depressed market conditions. The general behavior of the system is quite in keeping with what would be expected. Since there is no noise in the model, things change smoothly for the most part, with freight rates being the notable exception.

It is interesting to note here the difference between the least square straight line and smoothing process extrapolation methods. After the 10% step, both predictions rise at about the same rate reaching the 10% increase after about 22 months. The prediction based on the smoothing process peaks at about a 12% increase after about 47 months, and then decreases approaching the 10% point asymptotically. The least square prediction peaks at about a 14% increase after about 40 months, then decreases and at 60 months, and thereafter, gives an accurate prediction, since the demand is constant. It seems that the two extrapolation methods, in this case, give approximately equivalent results.

The major conclusion from this run was noted in the tanker ordering rates, comparing the oil companies with the independents. The usual practice has been that the independents are quick to place orders when the market improves, while the oil companies are slower to react, but do react. When the market drops, the independents are quick to cancel orders, while the oil companies have a firmer basis for their orders. This run, however, shows the oil companies ordering heavily at first, while the independents order very little more than previously. When the market collapses, the oil companies quickly cancel all they can, while the independents merely reduce their ordering rate. Because of this, the independent owners ordering decision will be revised before making any further computer runs. However, the other two runs mentioned were made with the original model (as reruns on the first run using the same computer code generation).

The second run, with the ramp input, showed the same basic character as the first run, except that the high freight rate lasted longer, about 60 months. This is understandable since the demand kept increasing with time and rose by 30% in the 60 months. Also, the market started turning up again about 40 months later as increased demand kept reducing the surplus of the depressed period. Thus, we see cyclical behavior in the model that is quite reasonable. Here too, however, the same comments apply regarding the new vessel ordering rates.

The third run, with noise, exhibits unusual characteristics. The freight rate swings back and forth between maximum and minimum values with complete randomness over relatively short periods of time. Obviously, the system has elements that are much too closely attuned to short run changes than should be the case. In addition, the noise is actually amplified to some extent by the fluctuations it causes in average length of haul. This type of noise pattern is not actually the case. Demand moves around what may be regarded as the trend with yearly cycles, and any additional noise to this seasonality is not great at all, say about plus or minus 1%. Unfortunately, time did not permit any further runs with noise input, so that this question is not ~~really~~ completely settled. However, it can be noticed from Figure I that there seems also to be some seasonality in the freight rate, that is, peak values tend to occur during the winter months with lower rates during the summer months. This seems to indicate that the market is, in fact, sensitive to short run demand shifts, but not as sensitive as the third computer run would indicate.

It may be also observed that in all three runs the construction price rose to about twice its normal value during the favorable market conditions, which greatly increased the shipyards' backlog. It may, however, be advisable to relate this price to the total backlog and not to only the level of unstarted orders, since the shipyards view both in making their own decisions.

The new ordering rule for the independents was based on their view of their own market position. That is, for any predicted freight rate, they would desire to obtain a certain share of the market (as opposed to the oil company marine divisions). At a very high freight rate they would desire a greater share of the market than they presently have. At a very low freight rate, they desire much less than their present position (this is in aggregation; some may want to go out of business while others will wait for the next boom). At a normal freight rate, they will be content with maintaining their present position. These three conditions are put into a parabolic relationship:

$$RSM.K = (AA.K)\,(FRP.K)^2 + (BB.K)\,(FRP.K) + (DD.K) \quad (68,A)$$

$$MIS.K = (STO.K + OTI.K)/OTI.K \quad (69,A)$$

$$STO.K = (OTO.K)\,(PLDI) \quad (70,A)$$

$$AA.K = (MIS.K - 6.0)/7.5 \quad (71,A)$$

$$BB.K = (16 - MIS.K)\,/5 \quad (72,A)$$

$$DD.K = (MIS.K - 21)/15 \quad (73,A)$$ where RSM is Ratio of desired to actual Share of Market

FRP is Freight Rate, index, Predicted

AA, BB, DD are coefficients to suit specified conditions

MIS is Maximum desired Increase in Share of Market

STO is Share of market that is desired to be Taken Over, at maximum FRP

PLDI is Part of oil company market that is Desired by Independents, at maximum FRP

The above equation meets these three conditions: 1) when FRP is at a maximum (3.5), RSM = MIS, 2) when FRP is 1.0, RSM = 1.0, 3) when FRP is at a minimum (0.5), RSM = 0.0. We then have:

DSM.K = (RSM.K) (PSM.K) (74,A)

PSM.K = OTI.K/(OTI.K + OTO.K) (75,A) where DSM is Desired Share of Market

PSM is Present Share of Market

The total market is next predicted, which sets the goal for independent tanker ownership.

PRI.K = (DSM.K) (PFI.K)/NIFI (76,A)

PFI.K = (PDI.K) (NALH) (CONV) (77,A)

PDI.K = PPD1.K + (PSD1.K) (TLTI) (78,A) where PRI is Predicted ownership Requirements, Independents, T-2s

PFI is Predicted Fleet requirements by Independents, T-2s

NIFI is Normal Idle Fleet factor, Independents

PDI is Predicted Demand for oil Independents, bbl/day

TLTI is Time for Long Term considerations, Independents, months

Though TLTI may differ from that for the oil companies, the same predicted freight rate is used since it is not felt that this refinement would be justified. The desired ordering rate is then established.

DOI.K = (PRI.K - POI.K) /NDI.K (79,A)

NDI.K = NXI.K, if NXI.K $>$ MNDI

MNDI, if NXI.K $\leq$ MNDI (80,A)

NXI.K = TLTI - EDT.K (81,A) where DOI is Desired Order rate, Independents, T-2/months

POI is Predicted Ownership, Independents, T-2s

NDI is Negotiation time for ordering, Independents, months

NXI is Negotiation time, actual, Independents, months

EDT is Estimated Delivery Time, shipyards, months

The independents have to predict how many vessels they will have, which compared to their previously established requirements determined the desired order rate.

POI.K = OTI.K + PNI.K - PSI.K (82,A)

PNI.K = TBI.K, if NCDS $>$ EDT.K

TBX.K, if NCDS $<$ EDT.K (83,A)

NCDS = SNBS + TCAS (84,N)

TBX.K = (TBI.K) (NCDS)/EDT.K (85,A)

PSI.K = (RSPI.K) (TLTI) (86,A)

RSPI.K = (MSI.K) e $^{(XPPI.K)}$ (87,A)

XPPI.K = (FRP.K) logn (NRSI) (88,A) where PNI is Predicted New vessels, Independents, T-2s

PSI is Predicted Scrappage, Independents, T-2s

TBI is Total Backlog at shipyard, Independents, T-2s

TBX is part of TBI that is expected to be delivered if EDT $>$ NCDS, T-2s

NCDS is Normal total Construction Delay at Shipyards, month

RSPI is Rate of Scrappage, Predicted, Independents, T-2/month

XPPI is Predicted value of XPI

The above is based on a value of TLTI not much larger than NCDS, but not at all smaller. This seems to be reasonable. The actual ordering rate is only limited by not being able to cancel non-existing orders.

MOI.K = - UIS.K/DT (89,A)

TOI.K = DOI.K, if DOI.K $>$ MOI.K

= MOI.K, if DOI.K $<$ MOI.K (90,R) where MOI is Minimum Ordering rate, Independents, T-2/month

UIS is Unstarted orders of Independents, at Shipyards, T-2s

TOI is Tanker Ordering rate, Independents, T-2/month

The foregoing decision rule formulation definitely allows for cancellations and is quite flexible, in that policy considerations can greatly affect it. The parameters required for this modification to the model are:

TLTI = 36 months

MNDI = 1.5 months

PLDI = 0.40

NIFI = 0.96

This value of PLDI means that at a maximum predicted freight rate, the independents ordering goal will be to take over 40% of the oil companies share of the market. These equations replace equations (69), (75), (79), and (90) of the original model. The initial conditions for these equations are the same as for the previous decision rule.

Having thusly revised the original model, two more runs were made (see Dynamo Run Nos. 1001 and 1002). The first run had a 10% step disturbance, while the second had the same ramp disturbance that was used previously. Both of these runs showed one dominant feature, that is, the new tanker ordering by the independents was extremely high, unrealistically so. The independents backlog grew to as high as four times the total fleet of existing tankers. After an extensive and lengthy investigation two reasons for this unusual occurrence were found. Unfortunately, time did not permit its correction, and the subsequent computer runs.

The first reason lies in equation (68) which relates predicted freight rate to the ratio of desired to actual share of the market. This equation was formulated to show the increase of the independents' goals of market strength as the predicted freight rate increased. The desired curve of this relationship started at a ratio of zero for the minimum freight rate, 0.5, rose to a ratio of one at the normal freight rate, 1.0, and then rises gradually to a ratio equal to MIS (Maximum desired Increase in Share of market) at the maximum freight rate, 3.5. After closer scrutiny of the equation as formulated, it is found to go through the three points specified, but in addition has a peak value of about twice what its maximum value should have been at a predicted freight rate of about 2.3. This caused the ordering rate to be abnormally high when the predicted freight rate was between 1.0 and 3.5. This phenomenon can be noticed by observing the peaks in the ordering curve as the predicted freight rate passes through this region.

However, even when the predicted freight rate was at a value of 3.5, indicating a favorable market attitude, and avoiding the formerly described error, the ordering was excessively high. This is especially noticeable in the second boom period of the computer results. The reason can be found in equation (189), which estimates the delivery time on new tankers order. The estimate is quite simply the total backlog divided by the present delivery rate. This estimate is good if there are no sharp changes in the rate at which orders are placed. What happened in this case, however, was that after the extended depression period a sudden burst of orders started coming in. The current delivery rate does not react very quickly to this. Therefore, there was a very high backlog compared to delivery rate, the estimated delivery time was very, very long, and so the amount of new vessels that would be delivered (PNI) was far below what it should have been. This caused the high ordering rate to persist.

It is hoped that others may benefit by this description of the difficulties in the revised decision rule. It is indeed unfortunate that time prevented their correction, especially since most other aspects of system behavior were found to be quite reasonable. It is further hoped that further work with this model may improve it in other ways, of which this author is sure there are many.

In general, however, it was felt that the model behavior was good, in that it showed responses that were logical and reasonable. Thus, it seems that many of the assumptions and omissions made are, in fact, not prime determinants of industry behavior. The rate at which orders are placed for new vessels is, on the other hand, a highly important determinant of the cyclical behavior. The ultimate refinement of these decision rules could lead to results which would be very illustrative of the forces behind the cyclic pattern.

V. CONCLUSIONS

A dynamic model of the tankship industry has been formulated. Its behavior is in general reasonable, compared to actual behavior patterns, but certain parts of it need additional revision. Time prevented this author from proceeding in that direction.

The model contains seven sectors and is built around a functional design of the industry. The supply department, oil companies, receives the demand for oil and generates the demand for tankers, as well as predictions of oil demand. The chartering department, oil company marine divisions, generates the voyage chartering rate based on short run demands and predictions. The operating department, oil company marine divisions, keeps track of the vessels and transfers them as required. The independent owners sector, includes all their functions, new tanker ordering, scrappage, and transfer of their fleet. The tankship brokers handle signed but unstarted charters, establish the prevailing freight rate, and generate predictions of the freight rate. The coordination department, oil company marine divisions, generates the long term policy decisions of new tanker ordering, scrappage, and time chartering rate. The shipyard sector transforms the orders for new vessels into subsequent tanker deliveries. All of these sectors are related to each other through information flows. Major consideration has been given to the role that expectations and predictions of the future play in the decision-making processes. Major assumptions made in formulation of the model include average length of haul is constant over long run, oil companies employ their own vessels if at all possible, short-run unsatisfied demand is made up when vessels are available, demand is met regardless of freight rate if vessels are available, and the static short-run supply curves is fixed over time. Some of the major considerations that are not included in the model are financial or funds flow influences, technological and size changes in ships, governmental restrictions, time charter freight rates, the cost of new construction, and the role of operating costs and revenues in decision analysis.

In spite of the many simplifications made, and perhaps more could have been soundly incorporated, the general system behavior is quite in accord with what would be expected of the real world. This model is, however, only an initial probing of the problem and much more remains to be done. Some of this is indicated herein. One area of tremendous importance has been recognized, that is, the new vessel ordering decisions. It is this aspect of the system that essentially stimulates cyclical behavior patterns. It is felt that the model presented here can serve as a foundation structure upon which to develop more fully this area of investigation, and as a guide in such development.

VI. RECOMMENDATIONS FOR FURTHER WORK

The first area requiring further work is the independent owners new vessel ordering rate. The difficulties encountered, as described in Chapter IV, can be remedied without too much difficulty. Further analysis of subsequent computer runs should eventually lead to decision rules that are reasonable.

Computer runs can then be made to investigate the effects of various changes in the model, either in parameters or policy statements, upon the system response. This would not only give insight into more of the forces behind the cyclical behavior, but also permit continual refinement of the model.

The tankship industry poses a problem, in its cyclical behavior, that seems to be, at first glance, quite amenable to analysis by the methods of industrial dynamics. This work has shown clearly that industrial dynamics can be used effectively to investigate such a problem, which is intimately related to dynamic changes in the tankship industry. It is hoped that further work can build upon this in gaining a sounder understanding of the ups and downs in the tankship market.

BIBLIOGRAPHY AND REFERENCES

References

(1) Koopmans, Tjalling, "Tanker Freight Rates and Tankship Building," P. S. King & Son, Ltd., London, 1939.

(2) Forrester, Jay W., "Definitions of Industrial Dynamics," Memorandum D-59 (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, December 2, 1959.

(3) Forrester, Jay W., "Industrial Dynamics - A Major Breakthrough for Decision Makers," Harvard Business Review, Vol. 36, July-August, 1958.

(4) Forrester, Jay W., "Models of Dynamic Behavior of Industrial and Economic Systems - A Section of Industrial Dynamics Class Notes," Memorandum D-46, (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, August 1, 1959.

(5) Fox, P., A. Pugh, G. Duren, E. Roberts, D. Howard, "DYNAMO II, an IBM 704 Program for Generating Dynamic Models," Memorandum D-47, (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, July 24, 1959.

(6) Duren, G., P. Fox, A. Pugh, "Addendum 1 (DYNAMO IIa) to Industrial Dynamics Memo D-47," Memorandum D-60, (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, December 1, 1959.

(7) Howard, D. J., "Procedure for Constructing and Submitting a Model to be Run by DYNAMO," Memorandum D-53, (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, January 11, 1960.

(8) Bes, J., "Tanker Chartering and Management," C. de Boer, Jr., Amsterdam, 1956.

(9) Kahle, Loren F., "Tanker Surplus Will Get Bigger," Oil and Gas Journal, Vol. 56, December 29, 1958.

(10) Kahle, Loren F., and A. J. Kelley, Jr., "The Role of Sea Transportation in the Petroleum Industry," Fifth World Petroleum Congress, 1959.

(11) Kahle, Loren F., "Surplus in Growing, But New Deliveries Continue," Oil and Gas Journal, Vol. 57, December 28, 1959.

(12) Winterbottom, John J., " Tanker Surplus Continues to Increase " , Oil and Gas Journal, Vol. 53, December 27, 1954.

(13) Zannetos, Zenon S., "The Theory of Oil Tankship Rates," Ph. D. Thesis, Department of Economics and Social Sciences, Massachusetts Institute of Technology, Cambridge 1959.

(14) Wylie, C. R., Jr., "Advanced Engineering Mathematics," McGraw-Hill Book Company, Inc., New York, 1951.

(15) Howard, David J., "Description of the Model of Production, Scheduling and Customer Delay as Used in 1959 Summer Session," Memorandum D-51, (an unpublished paper), Industrial Dynamics Group, School of Industrial Management, Massachusetts Institute of Technology, Cambridge, August 24, 1959.

APPENDIX

APPENDIX A

LEAST SQUARE STRAIGHT LINE CURVE FIT

The theoretical presentation of the method of least square may be found in reference (14) (p. 527). If we have a set of N points in the X Y plane, we wish to find an equation such as $y = a + bx$, that is a straight line, and that gives the best fit to the given points. The two unknowns are a and b, the y axis intercept and the slope respectively. The equations for finding these values are derived in the above mentioned reference and are:

$$Na + bX = Y \qquad (A1)$$

$$aX + bXX = XY \qquad (A2)$$

where X is the summation of all x values

Y is the summation of all y values

XX is the summation of all xx values

XY is the summation of all xy values.

solving for a and b, we can get:

$$a = (CA)\,(Y) + (CB)\,(XY)$$

$$b = (CC)\,(Y) + (CD)\,(XY)$$

where CA = XX/DENM

CB = X/DENM

CC = X/DENM

CD = N/DENM

DENM = N(XX) - (X) (X)

These two unknowns, a and b, are actually PPD1 and PSD1 when considering time as the X coordinate, with the present as zero. One must take care, however, for if they measure time positively going into the past they must change the sign of the resulting slope, PSD1. See Appendix C, supply department, for the actual equations used to generate the least square straight line.

APPENDIX B

DIFFERENTIAL EQUATION PREDICTION TECHNIQUE

The problem posed is to accurately predict the future levels in third order exponential delays based on certain assumptions as to the future input rates. The output rates are, of course, determined by the character of the exponential delays themselves. The method employed is straight-forward in nature. The differential equations of the levels are set up and solved as functions of time.

The case in point involves the level of negotiated but unstarted time charters and the level of vessels on time charters. The rate of vessels going into charter operation, from the first level, is a third order exponentially delayed value of the rate of signing charters, that is, the input rate to the level. The rate at which vessels leave the second level, of vessels in operation, is a third order exponentially delayed value of the rate at which they enter operation. Thus, we essentially have a sixth order delay between the signing of charters and their completion. However, the delay is different in the first three cascades from the second third order delay. The question then is: what will be the total of vessels in operation, that is, in the last three stages, after an arbitrary length of time if the signing of charters is stopped completely (input rate goes to zero)? Based on the answer to this question, and other factors involved, a decision will be made as to how many vessels to actually charter.

From the level equations of each of the six cascaded first order delays, we can derive the differential equations for the rate of change of the level. Calling the six levels, L1, L2, L3, L4, L5, and L6, and the outflow rates from these, R1, R2, R3, R4, R5, and R6, respectively, we can write these twelve equations:

L1' = 0.0 - R1	R1 = L1/T1
L2' = R1 - R2	R2 = L2/T1
L3' = R2 - R3	R3 = L3/T1
L4' = R3 - R4	R4 = L4/T2
L5' = R4 - R5	R5 = L5/T2
L6' = R5 - R6	R6 = L6/T2

where the primes ('s) indicate the first derivative with respect to time, and T1 and T2 are the delay constants. By substituting the values of the rates in terms of levels and time constants into the equations on the left we remain with six equations and six unknowns. The first equation has only one unknown, L1, since the input rate is assumed (given here as 0.0, but it may be any function of time). Therefore, this equation can be solved independently. Since the second equation involves only L2 and L1, as soon as the first equation is solved for L1, as a function of time, this value of L1 can be substituted in the second equation. Then this second equation can be solved for L2. This process is continued until L6 is solved for as a function of time. The solution will involve powers of e to functions of time and the delay constants, and coefficients based on the initial conditions, which in this case are the present values of the respective levels.

The actual equations derived and used are in Appendix C in the coordination department. As a check upon these equations, and the method used (which assumes an infinitesimal solution time interval), a computer run was made which only included the necessary rates and levels, and the prediction equations (see Dynamo Run No. 1029, Industrial Dynamics Files, School of Industrial Management, M.I.T.). This run verified both the method and the equations to complete satisfaction. The predictions were within about 0.5% of the actually generated values. This discrepancy is probably caused by the finite solution time interval used.

The author wishes to acknowledge the generous assistance rendered by Mr. Donald Aucamp, of the Industrial Dynamics Group, School of Industrial Management, M.I.T., in deriving the above method and getting the solution started.

APPENDIX C

EQUATIONS OF THE MODEL, FIRST REVISION

```
NOTE   TANKSHIP INDUSTRY MODEL, INCLUDING REVISED INDEPENDENT
NOTE                                OWNERS NEW VESSEL ORDERING DECISION RULE
NOTE                                                                       AR0000
NOTE                                                                       AR0000
NOTE   SUPPLY DEPARTMENT, OIL COMPANIES                                    AR0000
NOTE                                                                       AR0000
NOTE   SYSTEM EQUATIONS                                                    AR0000
37B    RHDO=BOXLIN(2,STIN)                                                 AR0101
20R    RDH.KL=PDO.K/STIN                                                   AR0102
1L     RHDO*1.K=RHDO*1.J+(DT)(RDH.JK+0.0)                                  AR0103
37B    PHDO=BOXLIN(30,STIN)                                                AR0104
6A     PHDO*1.K=RHDO*2.K                                                   AR0105
53N    S1=SUM1(30,TOCN)                                                    AR0107
53A    S2.K=SUM1(30,PHDO)                                                  AR0108
55N    S3=SUM2(30,TOCN,TOCN)                                               AR0109
55A    S4.K=SUM2(30,TOCN,PHDO)                                             AR0110
15N    DENM=(NPUF)(S3)+(-S1)(S1)                                           AR0111
20N    CA=S3/DENM                                                          AR0112
20N    CB=-S1/DENM                                                         AR0113
42N    CC=-S1/((DENM)(STIN))                                               AR0114
42N    CD=NPUF/((DENM)(STIN))                                              AR0115
15A    PPD1.K=(CA)(S2.K)+(CB)(S4.K)                                        AR0116
15A    PSD1.K=(-CC)(S2.K)+(CD)(-S4.K)                                      AR0117
3L     SDO.K=SDO.J+(DT)(1/TSDO)(PDO.J-SDO.J)                               AR0118
6R     RDO.KL=SDO.K                                                        AR0119
39R    DDO.KL=DELAY3(RDO.JK,TDDO)                                          AR0120
21A    PSD2.K=(1/TDDO)(SDO.K-DDO.JK)                                       AR0121
14A    PPD2.K=SDO.K+(PSD2.K)(TSDO)                                         AR0122
13A    PDT.K=(PDO.K)(ALH.K)(CONV)                                          AR0123
14A    ALH.K=MALH+(DALH)(RPD.K)                                            AR0124
20A    RPD.K=PDO.K/PPD1.K                                                  AR0125
7N     DALH=NALH-MALH                                                      AR0126
NOTE                                                                       AR0000
NOTE   SYSTEM PARAMETERS                                                   AR0000
```

```
C     TOCN*=1.0/2.0/3.0/4.0/5.0/6.0/7.0/8.0/9.0/10.0/11.0/12.0/13.0/14.0    AR0100
X1    /15.0/16.0/17.0/18.0/19.0/20.0/21.0/22.0/23.0/24.0/25.0/26.0/27.0/    AR0100
X2    28.0/29.0/30.0                                                         AR0100
NOTE  NPUF=TFST/STIN                                                         AR0106
NOTE  TFST=60.0                                                              AR0248
C     NPUF=30/STIN=2.0                                                       AR0175
C     TSDO=30/TDDO=30                                                        AR0177
C     CONV=.00000003/NALH=4000/MALH=3000                                     AR0191
NOTE                                                                         AR0000
NOTE  INITIAL CONDITIONS                                                     AR0000
C     RHDO*=0.0/10000000                                                     AR0349
20N   RDH=SDO/STIN                                                           AR0472
C     PHDO*=10000000/10000000/10000000/10000000/10000000/10000000/100000    AR0351
X1    00/10000000/10000000/10000000/10000000/10000000/10000000/10000000/    AR0351
X2    10000000/10000000/10000000/10000000/10000000/10000000/10000000/100    AR0351
X3    00000/10000000/10000000/10000000/10000000/10000000/10000000/100000    AR0351
X4    00/10000000                                                            AR0351
6N    SDO=10000000                                                           AR0458
6N    RDO=SDO                                                                AR0357
NOTE                                                                         AR0000
NOTE                                                                         AR0000
NOTE  CHARTERING DEPARTMENT, OIL COMPANY MARINE DIVISIONS                    AR0000
NOTE                                                                         AR0000
NOTE  SYSTEM EQUATIONS                                                       AR0000
8A    OPO.K=OTO.K+DPO.K-SPO.K                                                AR0127
18A   DPO.K=(NMDA)(PID.K+TDO.JK)                                             AR0128
18A   SPO.K=(NMDA)(PIS.K+RSO.JK)                                             AR0129
44A   PID.K=(PCD.K)(NMDA)/2.0                                                AR0459
44A   PIS.K=(PCS.K)(NMDA)/2.0                                                AR0131
21A   PCD.K=(1/TSTD)(TDO.JK-TDS.K)                                           AR0132
21A   PCS.K=(1/TSRS)(RSO.JK-RSS.K)                                           AR0133
3L    TDS.K=TDS.J+(DT)(1/TSTD)(TDO.JK-TDS.J)                                 AR0134
3L    RSS.K=RSS.J+(DT)(1/TSRS)(RSO.JK-RSS.J)                                 AR0135
8A    TPT.K=TOT.K+TPO.K-TPI.K                                                AR0136
```

```
18A   TPO.K=(NMDA)(PIO.K+RTO.JK)                                   AR0137
18A   TPI.K=(NMDA)(PII.K+RTI.JK)                                   AR0138
44A   PIO.K=(PCO.K)(NMDA)/2.0                                      AR0139
44A   PII.K=(PCI.K)(NMDA)/2.0                                      AR0140
21A   PCO.K=(1/TSRO)(RTO.JK-ROS.K)                                 AR0141
21A   PCI.K=(1/TSRI)(RTI.JK-RIS.K)                                 AR0142
3L    ROS.K=ROS.J+(DT)(1/TSRO)(RTO.JK-ROS.J)                       AR0143
3L    RIS.K=RIS.J+(DT)(1/TSRI)(RTI.JK-RIS.J)                       AR0144
7A    EST.K=OPO.K+TPT.K                                            AR0145
7A    TAP.K=PDT.K-EST.K                                            AR0146
44A   TOP.K=(NMDA)(TAP.K)/TCVC                                     AR0147
21R   CRD.KL=(1/TNVC)(TOP.K-CVN.K)                                 AR0224
2L    UDV.K=UDV.J+(DT)(CRD.JK-CRV.JK+URV.JK+0.0+0.0+0.0)           AR0267
27R   CRV.KL=(UDV.K/TUDV)+CRD.JK                                   AR0268
NOTE
NOTE  SYSTEM PARAMETERS                                            AR0000
C     NMDA=3/TSTD=6/TSRS=6                                         AR0442
C     TSRO=6/TSRI=6                                                AR0200
C     TNVC=1.0/TUDV=12.0                                           AR0201
NOTE
NOTE  INITIAL CONDITIONS                                           AR0000
6N    TDS=TDO                                                      AR0363
6N    RSS=RSO                                                      AR0364
6N    ROS=RTO                                                      AR0365
6N    RIS=RTI                                                      AR0366
6N    CRD=RVO                                                      AR0397
6N    UDV=0.0                                                      AR0396
6N    CRV=CRD                                                      AR0398
NOTE                                                               AR0000
NOTE                                                               AR0000
NOTE  OPERATING DEPARTMENT, OIL COMPANY MARINE DIVISIONS           AR0000
NOTE
NOTE  SYSTEM EQUATIONS                                             AR0000
1L    OTO.K=OTO.J+(DT)(TDO.JK-RSO.JK)                              AR0052
```

```
1L    ITO.K=ITO.J+(DT)(0.0-ROT.JK)                                     AR0510
2L    TOC.K=TOC.J+(DT)(ROT.JK-RSO.JK+TDO.JK+0.0+0.0+0.0)               AR0511
20A   MRT.K=ITO.K/TNOO                                                 AR0228
26A   DRT.K=(OPO.K+TAP.K-TOC.K)/(NMDA+0.0+0.0)                         AR0229
51A   TRO.K=CLIP(MRT.K,DRT.K,TAP.K,0.0)                                AR0230
20A   ULR.K=ITO.K/DT                                                   AR0231
20A   LLR.K=-TOC.K/DT                                                  AR0232
51A   STR.K=CLIP(ULR.K,TRO.K,TRO.K,ULR.K)                              AR0233
51R   ROT.KL=CLIP(STR.K,LLR.K,STR.K,LLR.K)                             AR0234
NOTE
NOTE  SYSTEM PARAMETERS                                                AR0000
C     TNOO=0.5                                                         AR0444
NOTE
NOTE  INITIAL CONDITIONS                                               AR0000
6N    OTO=480                                                          AR0460
6N    ITO=0.0                                                          AR0368
6N    ROT=0                                                            AR0547
6N    TOC=OTO                                                          AR0370
NOTE                                                                   AR0000
NOTE                                                                   AR0000
NOTE  INDEPENDENT OWNERS                                               AR0000
NOTE
NOTE  SYSTEM EQUATIONS                                                 AR0000
1L    OTI.K=OTI.J+(DT)(TDI.JK-RSI.JK)                                  AR0053
2L    ITI.K=ITI.J+(DT)(TDI.JK+RVI.JK+RTI.JK-RVO.JK-RTO.JK-RSI.JK)      AR0054
1L    TOV.K=TOV.J+(DT)(RVO.JK-RVI.JK)                                  AR0055
39R   RVI.KL=DELAY3(RVO.JK,TCVC)                                       AR0059
1L    TOT.K=TOT.J+(DT)(RTO.JK-RTI.JK)                                  AR0056
1L    OT1.K=OT1.J+(DT)(RTO.JK-TI1.JK)                                  AR0157
20R   TI1.KL=OT1.K/TAU2                                                AR0158
1L    OT2.K=OT2.J+(DT)(TI1.JK-TI2.JK)                                  AR0159
20R   TI2.KL=OT2.K/TAU2                                                AR0160
1L    OT3.K=OT3.J+(DT)(TI2.JK-RTI.JK)                                  AR0161
20R   RTI.KL=OT3.K/TAU2                                                AR0162
```

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18A   YUI.K=(JTI.JK)(JFI.JK+DTYR)                                        AR0254
13A   YSI.K=(RSI.JK)(DT)(LASI.JK)                                        AR0255
21A   AFI.K=(1/OTI.K)(YUI.K-YSI.K)                                       AR0256
14A   XAI.K=-MULI+(3.0)(AFI.K)                                           AR0259
46A   MSI.K=(OTI.K)(XAI.K)(XAI.K)/((AFI.K)(AFI.K)(108.0))                AR0260
29A   XPI.K=(FRV.K)LOGN(NRSI)                                            AR0257
28R   RSI.KL=(MSI.K)EXP(XPI.K)                                           AR0258
12A   ASI.K=(AFI.K)(ASCR)                                                AR0461
6R    LASI.KL=ASI.K                                                      AR0446
6R    JTI.KL=OTI.K                                                       AR0252
6R    JFI.KL=AFI.K                                                       AR0253
21A   MIS.K=(1/OTI.K)(STO.K+OTI.K)                                       AR0487
12A   STO.K=(OTO.K)(PLDI)                                                AR0517
21A   AA.K=(1/7.5)(MIS.K-6.0)                                            AR0488
21A   BB.K=(1/5)(16-MIS.K)                                               AR0489
21A   DD.K=(1/15)(MIS.K-21)                                              AR0490
17A   RSM.K=(AA.K)(FRP.K)(FRP.K)+(BB.K)(FRP.K)(1)+(DD.K)(1)(1)           AR0491
12A   DSM.K=(RSM.K)(FSM.K)                                               AR0492
26A   PSM.K=(OTI.K+0.0+0.0)/(OTI.K+OTO.K+0.0)                            AR0518
44A   PRI.K=(DSM.K)(PFI.K)/NIFI                                          AR0538
13A   PFI.K=(PDI.K)(NALH)(CONV)                                          AR0495
14A   PDI.K=PPDI.K+(PSDI.K)(TLTI)                                        1R0496
21A   DOI.K=(1/NDI.K)(PRI.K-POI.K)                                       AR0497
51A   NDI.K=CLIP(NXI.K,MNDI,NXI.K,MNDI)                                  AR0498
7A    NXI.K=TLTI-EDT.K                                                   AR0499
8A    POI.K=OTI.K+PNI.K-PSI.K                                            AR0500
51A   PNI.K=CLIP(TBI.K,TBX.K,NCDS,EDT.K)                                 AR0501
7N    NCDS=SNBS+TCAS                                                     AR0502
44A   TBX.K=(TBI.K)(NCDS)/EDT.K                                          AR0503
12A   PSI.K=(RSPI.K)(TLTI)                                               AR0504
23A   RSPI.K=(MSI.K)EXP(XPPI.K)                                          AR0505
29A   XPPI.K=(FRP.K)LOGN(NRSI)                                           AR0506
20A   MOI.K=-UIS.K/DT                                                    AR0507
51R   TOI.KL=CLIP(DOI.K,MOI.K,DOI.K,MOI.K)                               AR0508
```

```
NOTE
NOTE   SYSTEM PARAMETERS                                  AR0000
C      TCVC=1.5/TCTC=54.0                                 AR0176
C      MULI=23/NRSI=.73469388/ASCR=2.5                    AR0463
C      TLTI=36/MNDI=1.5/PLDI=.20                          AR0546
C      NIFI=0.96                                          AR0539
NOTE
NOTE   INITIAL CONDITIONS                                 AR0000
6N     OTI=770                                            AR0464
6N     ITI=50.0                                           AR0372
6N     TOV=180                                            AR0465
20N    RVO=TOV/TCVC                                       AR0374
6N     TOT=540                                            AR0466
20N    RTO=TOT/TCTC                                       AR0376
20N    OT1=TOT/3.0                                        AR0377
6N     TI1=RTO                                            AR0378
20N    OT2=TOT/3.0                                        AR0379
6N     TI2=TI1                                            AR0380
20N    OT3=TOT/3.0                                        AR0381
6N     RTI=TI2                                            AR0382
6N     JTI=OTI                                            AR0383
6N     JFI=10                                             AR0467
12N    LASI=(JFI)(ASCR)                                   AR0468
46N    RSI=(OTI)(49)(NRSI)/((JFI)(JFI)(108))              AR0469
6N     TOI=RSI                                            AR0438
NOTE                                                      AR0000
NOTE                                                      AR0000
NOTE   TANKSHIP BROKERS                                   AR0000
NOTE
NOTE   SYSTEM EQUATIONS                                   AR0000
59A    ERV.K=TABLE(ERVT,PTE.K,0.50,1.00,0.01)             AR0476
26A    PTE.K=(TOV.K+TOT.K+TOC.K)/(OTO.K+OTI.K+0.0)        AR0264
1L     CVN.K=CVN.J+(DT)(CRV.JK-DRV.JK)                    AR0265
39R    DRV.KL=DELAY3(CRV.JK,TBVO)                         AR0266
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44A   MRV.K=(ITI.K)(MPRV)/DT                                          AR0269
51R   RVO.KL=CLIP(DRV.JK,MRV.K,MRV.K,DRV.JK)                          AR0270
7A    XRV.K=DRV.JK-MRV.K                                              AR0271
51R   URV.KL=CLIP(XRV.K,0.0,XRV.K,0.0)                                AR0272
1L    CTN.K=CTN.J+(DT)(CRT.JK-RTO.JK)                                 AR0150
1L    TN1.K=TN1.J+(DT)(CRT.JK-TO1.JK)                                 AR0151
20R   TO1.KL=TN1.K/TAU1                                               AR0152
1L    TN2.K=TN2.J+(DT)(TO1.JK-TO2.JK)                                 AR0153
20R   TO2.KL=TN2.K/TAU1                                               AR0154
1L    TN3.K=TN3.J+(DT)(TO2.JK-RTO.JK)                                 AR0155
44A   MCT.K=(ITI.K)(MPRT)/DT                                          AR0274
7N    MPRT=1.000-MPRV                                                 AR0275
51R   RTO.KL=CLIP(DCT.JK,MCT.K,MCT.K,DCT.JK)                          AR0276
20R   DCT.KL=TN3.K/TAU1                                               AR0277
3L    FVS.K=FVS.J+(DT)(1/TSFR)(FRV.J-FVS.J)                           AR0294
21A   FRC.K=(1/TSFR)(FRV.K-FVS.K)                                     AR0295
44A   FRD.K=(TLTC)(FRC.K)/2.0                                         AR0296
7A    FRX.K=FRV.K+FRD.K                                               AR0297
51A   FRY.K=CLIP(FRX.K,FRVM,FRVM,FRX.K)                               AR0298
51A   FRP.K=CLIP(FRY.K,FRVL,FRY.K,FRVL)                               AR0299
NOTE
NOTE  SYSTEM PARAMETERS                                               AR0000
C     FRVT*=.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/ AR0480
X1    .5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.5/.51/.51/.52/.53/.54/.55/.57 AR0480
X2    /.59/.61/.63/.67/.73/.82/1.0/1.6/3.5/3.5/3.5                    AR0480
C     TBVO=2/TBTO=20                                                  AR0443
C     MPRV=0.930                                                      AR0273
C     TSFR=3.0/FRVL=0.50/FRVM=3.50                                    AR0301
NOTE
NOTE  INITIAL CONDITIONS                                              AR0000
12N   CVN=(CRV)(TBVO)                                                 AR0395
6N    URV=0.0                                                         AR0399
12N   CTN=(CRT)(TBTO)                                                 AR0400
20N   TN1=CTN/3.0                                                     AR0401
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6N      TO1=CRT                                                   AR0402
20N     TN2=CTN/3.0                                               AR0403
6N      TO2=TO1                                                   AR0404
20N     TN3=CTN/3.0                                               AR0405
6N      DCT=TO2                                                   AR0406
6N      FVS=1.00                                                  AR0473
NOTE                                                              AR0000
NOTE                                                              AR0000
NOTE    COORDINATION DEPARTMENT, OIL COMPANY MARINE DIVISIONS     AR0000
NOTE
NOTE    SYSTEM EQUATIONS                                          AR0000
18A     YUO.K=(JTO.JK)(JFO.JK+DTYR)                               AR0240
20N     DTYR=DT/12.0                                              AR0284
13A     YSO.K=(RSO.JK)(DT)(LASO.JK)                               AR0241
21A     AFO.K=(1/OTO.K)(YUO.K-YSO.K)                              AR0242
14A     XAO.K=-MULO+(3.0)(AFO.K)                                  AR0245
46A     MSO.K=(OTO.K)(XAO.K)(XAO.K)/((AFO.K)(AFO.K)(108.0))       AR0246
29A     XPO.K=(FRV.K)LOGN(NRSO)                                   AR0243
28R     RSO.KL=(MSO.K)EXP(XPO.K)                                  AR0244
12A     ASO.K=(AFO.K)(ASCR)                                       AR0462
6R      LASO.KL=ASO.K                                             AR0445
6R      JTO.KL=OTO.K                                              AR0238
6R      JFO.KL=AFO.K                                              AR0239
20N     EXP1=-TLTC/TAU1                                           AR0163
20N     EXP2=-TLTC/TAU2                                           AR0164
28N     EP11=(1.0)EXP(EXP1)                                       AR0165
12N     EP12=(TLTC)(EP11)                                         AR0166
12N     EP13=(TLTC)(EP12)                                         AR0167
28N     EP21=(1.0)EXP(EXP2)                                       AR0168
12N     EP22=(TLTC)(EP21)                                         AR0169
12N     EP23=(TLTC)(EP22)                                         AR0170
7N      DBTT=TAU1-TAU2                                            AR0171
44N     CRTT=(TAU1)(TAU2)/DBTT                                    AR0172
20N     TAU1=TBTO/3.0                                             AR0173
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20N   TAU2=TCTC/3.0                                          AR0174
6A    C11.K=TN1.K                                            AR0178
6A    C12.K=TN2.K                                            AR0179
20A   C22.K=C11.K/TAU1                                       AR0180
6A    C13.K=TN3.K                                            AR0181
20A   C23.K=C12.K/TAU1                                       AR0182
42A   C33.K=C22.K/((2.0)(TAU1))                              AR0183
44A   C44.K=(CRTT)(C33.K)/TAU1                               AR0184
18A   C34.K=(CRTT)(R23.K-M44.K)                              AR0185
20A   R23.K=C23.K/TAU1                                       AR0186
12A   M44.K=(2.0)(C44.K)                                     AR0187
18A   C24.K=(CRTT)(R13.K-C34.K)                              AR0188
20A   R13.K=C13.K/TAU1                                       AR0189
7A    C14.K=OT1.K-C24.K                                      AR0190
44A   C55.K=(CRTT)(C44.K)/TAU2                               AR0192
18A   C45.K=(CRTT)(R34.K-M55.K)                              AR0193
20A   R34.K=C34.K/TAU2                                       AR0194
12A   M55.K=(2.0)(C55.K)                                     AR0195
18A   C35.K=(CRTT)(R24.K-C45.K)                              AR0196
20A   R24.K=C24.K/TAU2                                       AR0197
20A   C25.K=C14.K/TAU2                                       AR0198
7A    C15.K=OT2.K-C35.K                                      AR0199
44A   C66.K=(CRTT)(C55.K)/TAU2                               AR0202
18A   C56.K=(CRTT)(R45.K-M66.K)                              AR0203
20A   R45.K=C45.K/TAU2                                       AR0204
12A   M66.K=(C66.K)(2.0)                                     AR0205
18A   C46.K=(CRTT)(R35.K-C56.K)                              AR0206
20A   R35.K=C35.K/TAU2                                       AR0207
42A   C36.K=C25.K/((2.0)(TAU2))                              AR0208
20A   C26.K=C15.K/TAU2                                       AR0209
7A    C16.K=OT3.K-C46.K                                      AR0210
12A   FL1.K=(C11.K)(EP11)                                    AR0211
15A   FL2.K=(C12.K)(EP11)+(C22.K)(EP12)                      AR0212
16A   FL3.K=(C13.K)(EP11)+(C23.K)(EP12)+(C33.K)(EP13)+(0.0)(1.0)  AR0213
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16A   FL4.K=(C14.K)(EP21)+(C24.K)(EP11)+(C34.K)(EP12)+(C44.K)(EP13)        AR0214
16A   FL5.K=(C15.K)(EP21)+(C25.K)(EP22)+(C35.K)(EP11)+(1.0)(F5X.K)         AR0215
15A   F5X.K=(C45.K)(EP12)+(C55.K)(EP13)                                    AR0216
16A   FL6.K=(C16.K)(EP21)+(C26.K)(EP22)+(C36.K)(EP23)+(1.0)(F6X.K)         AR0217
16A   F6X.K=(C46.K)(EP11)+(C56.K)(EP12)+(C66.K)(EP13)+(0.0)(1.0)           AR0218
8A    FTN.K=FL1.K+FL2.K+FL3.K                                              AR0219
8A    FOTX.K=FL4.K+FL5.K+FL6.K                                             AR0220
7A    FTT.K=FTN.K+FOTX.K                                                   AR0221
8A    FOT.K=CTN.K+TOT.K-FLT.K                                              AR0485
12A   FLT.K=(TLTC)(RTI.JK)                                                 AR0486
14A   LPD.K=PPD1.K+(PSD1.K)(TLTC)                                          AR0285
13A   LPT.K=(LPD.K)(NALH)(CONV)                                            AR0286
8A    LPO.K=OTO.K+TBO.K-LPS.K                                              AR0287
12A   LPS.K=(RSP.K)(TLTC)                                                  AR0288
28A   RSP.K=(MSP.K)EXP(XPP.K)                                              AR0290
29A   XPP.K=(FRP.K)LOGN(NRSO)                                              AR0291
46A   MSP.K=(OTO.K)(XAP.K)(XAP.K)/((AFP.K)(AFP.K)(108.0))                  AR0292
14A   XAP.K=-MULO+(3.0)(AFP.K)                                             AR0293
6A    AFP.K=AFO.K                                                          AR0300
12A   LDO.K=(LPT.K)(PRO.K)                                                 AR0302
18A   LDT.K=(LPT.K)(PRT.K-PRO.K)                                           AR0303
59A   PRO.K=TABLE(PROT,FRP.K,0.50,3.50,0.10)                               AR0477
59A   PRT.K=TABLE(PRTT,FRP.K,0.50,3.50,0.10)                               AR0478
7A    POR.K=LDO.K-LPO.K                                                    AR0308
7A    NXO.K=TLTC-EDT.K                                                     AR0310
51A   NDO.K=CLIP(NXO.K,MNDO,NXO.K,MNDO)                                    AR0311
20A   DOO.K=POR.K/NDO.K                                                    AR0312
51R   TOO.KL=CLIP(DOO.K,MOO.K,DOO.K,MOO.K)                                 AR0313
20A   MOO.K=-UOS.K/DT                                                      AR0314
7A    PTR.K=LDT.K-FOT.K                                                    AR0315
7N    NTCO=TLTC-TBTO                                                       AR0316
20A   CTD.K=PTR.K/NTCO                                                     AR0317
14A   IPD.K=PPD1.K+(PSD1.K)(TIRC)                                          AR0318
13A   IPT.K=(IPD.K)(NALH)(CONV)                                            AR0319
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44A   IPI.K=(TIRC)(TUO.K)/TCAS                                              AR0320
8A    IPO.K=OTO.K+IPI.K-IPS.K                                               AR0321
12A   IPS.K=(RSO.K)(TIRC)                                                   AR0322
8A    ITC.K=TOT.K+IIT.K-IOT.K                                               AR0323
44A   IIT.K=(TIRC)(CTN.K)/TBTO                                              AR0324
44A   IOT.K=(TIRC)(TOT.K)/TCTC                                              AR0325
21A   IPC.K=(1/IPT.K)(IPO.K+ITC.K)                                          AR0326
59A   IRT.K=TABLE(PRTT,FRI.K,0.50,3.50,0.10)                                AR0479
44A   FRA.K=(TIRC)(FRC.K)/2.0                                               AR0434
7A    FRB.K=FRV.K+FRA.K                                                     AR0435
51A   FRG.K=CLIP(FRB.K,FRVM,FRVM,FRB.K)                                     AR0436
51A   FRI.K=CLIP(FRG.K,FRVL,FRG.K,FRVL)                                     AR0437
20A   ITP.K=IRT.K/IPC.K                                                     AR0328
30A   CTI.K=(1.0)SQRT(ITP.K)                                                AR0329
12R   CRT.KL=(CTD.K)(CTI.K)                                                 AR0330
NOTE
NOTE  SYSTEM PARAMETERS                                                     AR0000
C     TLTC=48.0                                                             AR0447
C     NRSO=0.80/MULO=18                                                     AR0475
C     PROT*=.250/.289/.321/.351/.378/.400/.420/.438/.453/.467/.479/.490/    AR0481
X1    .501/.511/.520/.529/.537/.544/.551/.558/.564/.569/.574/.578/.582/.    AR0481
X2    586/.589/.592/.595/.598/.600                                          AR0481
C     PRTT*=.750/.781/.802/.821/.837/.850/.862/.872/.880/.887/.894/.900/    AR0482
X1    .905/.910/.914/.918/.922/.925/.928/.930/.932/.934/.936/.938/.940/.    AR0482
X2    942/.944/.946/.948/.949/.950                                          AR0482
C     TIRC=9.0/MNDO=4                                                       AR0520
NOTE
NOTE  INITIAL CONDITIONS                                                    AR0000
6N    JTO=OTO                                                               AR0413
6N    JFO=8.0                                                               AR0474
12N   LASO=(JFO)(ASCR)                                                      AR0470
46N   RSO=(OTO)(36)(NRSO)/((JFO)(JFO)(108))                                 AR0471
6N    TOO=RSO                                                               AR0424
6N    CRT=RTO                                                               AR0425
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NOTE                                                                    AR0000
NOTE                                                                    AR0000
NOTE   SHIPYARD SECTOR                                                  AR0000
NOTE
NOTE   SYSTEM EQUATIONS                                                 AR0000
1L     UOS.K=UOS.J+(DT)(TOO.JK-TCO.JK)                                  AR0009
1L     UIS.K=UIS.J+(DT)(TOI.JK-TCI.JK)                                  AR0010
4L     SOS.K=SOS.J+(DT)(1/TSOS)(TOO.JK+TOI.JK-SOS.J+0.0+0.0+0.0)        AR0011
12A    UNS.K=(SOS.K)(SNBS)                                              AR0012
20A    EBS.K=SOS.K/OUTP                                                 AR0013
42A    EUS.K=DUS.K/((OUTP)(TOUS))                                       AR0014
7A     EDS.K=EBS.K+EUS.K                                                AR0015
8A     DUS.K=UIS.K+UOS.K-UNS.K                                          AR0016
1L     EAS.K=EAS.J+(DT)(HRS.JK-FRS.JK)                                  AR0017
7A     ECS.K=EDS.K-EAS.K                                                AR0018
12A    SCC.K=(EAS.K)(OUTP)                                              AR0019
51R    HRS.KL=CLIP(PHS.K,0.0,ECS.K,0.0)                                 AR0020
51R    FRS.KL=CLIP(PFS.K,0.0,-ECS.K,0.0)                                AR0021
20A    PHS.K=ECS.K/TIES                                                 AR0022
20A    PFS.K=-ECS.K/TDES                                                AR0023
17A    CPS.K=(CPMS)(1.0)(1.0)+(URS.K)(URS.K)(CPRS)+(0.0)(1.0)(1.0)      AR0071
21A    URS.K=(1/UNS.K)(UOS.K+UIS.K)                                     AR0025
7N     CPRS=CPNS-CPMS                                                   AR0026
26A    UOI.K=(UOS.K+0.0+0.0)/(UIS.K+UOS.K+0.0)                          AR0027
21A    CSL.K=(1/DT)(UOS.K+UIS.K)                                        AR0028
51A    TCT.K=CLIP(CSL.K,SCC.K,SCC.K,CSL.K)                              AR0029
12R    TCO.KL=(UOI.K)(TCT.K)                                            AR0030
18R    TCI.KL=(TCT.K)(1.0-UOI.K)                                        AR0031
1L     TUO.K=TUO.J+(DT)(TCO.JK-TDO.JK)                                  AR0032
1L     TUI.K=TUI.J+(DT)(TCI.JK-TDI.JK)                                  AR0033
39R    TDO.KL=DELAY3(TCO.JK,TCAS)                                       AR0034
39R    TDI.KL=DELAY3(TCI.JK,TCAS)                                       AR0035
7A     TBO.K=UOS.K+TUO.K                                                AR0282
7A     TBI.K=UIS.K+TUI.K                                                AR0283
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26A   EDT.K=(TBO.K+TBI.K+0.0)/(TDO.JK+TDI.JK+0.0)              AR0309
NOTE
NOTE  SYSTEM PARAMETERS
C     TSOS=72.0/SNBS=15.0/OUTP=0.0001/TOUS=60.0                AR0335
C     TIES=4.0/TDES=4.0                                        AR0085
C     CPMS=0.80/CPNS=1.00/TCAS=18.0                            AR0336
NOTE
NOTE  INITIAL CONDITIONS
12N   UOS=(SNBS)(TOO)                                          AR0038
12N   UIS=(SNBS)(TOI)                                          AR0039
7N    SOS=TOO+TOI                                              AR0040
21N   EAS=(1/OUTP)(TOO+TOI)                                    AR0041
12N   TUO=(TCAS)(TOO)                                          AR0042
12N   TUI=(TCAS)(TOI)                                          AR0043
6N    TCO=TOO                                                  AR0046
6N    TCI=TOI                                                  AR0047
NOTE
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APPENDIX D

GLOSSARY OF VARIABLES AND PARAMETERS

AA - coefficient to suit specified conditions
AFI - average Age of Fleet, Independents, years
AFO - " " " " , Oil companies, "
AFP - " " " " , oil " , Projected, yrs.
ALH - Average Length of Haul, miles
ASCR - Age of SCRappage as multiple of age of fleet
ASI - average Age of Scrappage, Independents, years
ASO - " " " " , Oil companies "
BB - coefficient to suit specified conditions
CONV - CONVersion factor, T-2/bbl-miles/day
CRD - Chartering Rate, voyage, to meet Demand, T-2/mon.
CRT - " " , Time, actual, T-2/mon.
CRV - " " , Voyage, actual, T-2/mon.
CSL - Construction Start Limiting rate, T-2/mon.
CTD - Chartering rate, Time, Desired, T-2/mon.
CTI - CorrecTion facter to CTD for Intermediate run
CTN - Chartered tankers, Time, Not yet in operation, T-2s
CVN - " " , Voyage, " " " " , "
DCT - Desired rate of Time charters going into operation, T-2/mon.
DD - coefficient to suit specified conditions
DDO - Delayed value of RDO
DOI - Desired Order rate, Independents, T-2/mon.
DOO - " " " , Oil companies, "
DPO - Deliveries, Projected, to Oil companies, T-2s
DRT - Desired Rate of Tansfer, oil cos., T-2/mon.
DRV - Desired Rate of Voyage charters going into operation, T-2/mon.
DSM - Desired Share of Market, independents
DTYR - solution time interval, years
DUS - Difference between actual and normal Unstarted backlog at Shipyards, T-2s
EAS - Employment Actual, at Shipyards, men
EBS - " desired for normal Business level, at Shipyards, men
ECS - Employment Change desiredm at Shipyards, men
EDS - " Desired, total, at " , "
EDT - Estimated Delivery Time, from shipyards, mon.
EST - " Supply of Tankers, oil companies, T-2s
EUS - Employment desired to correct size of Unstarted backlog at Shipyards, men
FLT - Future amount of vessels Leaving Time charters, T-2s
FOT - " number of vessels On Time charters, T-2s
FRA - intermediate change in FRV
FRB - " expected value of FRV
FRC - Freight Rate index rate of Change
FRD - long term change in FRV
FRG - trial value of FRI
FRI - Freight Rate index, predicted, Intermediate run
FRP - Freight " " , Predicted, long run
FRS - Firing Rate at Shipyard, men/mon.

FRV - Freight Rate index, Voyage
FRVL - minimum value of FRV
FRVM - Maximum " " "
FRVT - Tabular values of FRV
FRX - average long run value of FRV
FRY - second trial value of FRP
FVS - Freight rate index, Voyage, Smoothed
HRS - Hiring Rate at Shipyard, men/month
IIT - Intermediate Increase in Time chaters, T-2s
IOT - " decrease " " " , "
IPC - " Percentage of demand Covered by either owned or time chartered vessels
IPD - Intermediate Projected Demand for oil, bbl/day
IPI - " " Increase in owned vessels, T-2s
IPO - " " Ownership, T-2s
IPS - " " Scrappage, T-2s
IPT - " " demand for Tankers, T-2s
IRT - " desired Ratio of coverage to Total demand
ITC - " projected Time Charters, T-2s
ITI - Idle Tankers, Independents, T-2s
ITO - " " , Oil companies, T-2s
JFI - artificial rate (AFI)
JFO - " " (AFO)
JTI - " " (OTI)
JTO - " " (OTO)
LASI - " " (ASI)
LASO - " " (ASO)
LDO - Long term Desired Ownership, oil cos., T-2s
LDT - " " " Time charters, oil cos., T-2s
LLR - Lower Limit of Rate ROT, T-2/mon.
LPD - Long term Projected Demand for oil, bbl/day
LPO - " " " tanker Ownership, T-2s
LPS - " " " Scrappage, T-2s
LPT - " " " demand for Tankers, T-2s
MALH - Minimum Average Length of Haul, miles
MCT - Maximum value of RTO, T-2/mon.
MIS - " desired Increase in Share of market
MNDO - Minimum value of NDO, mon.
MOI - Minimum Order rate, Independents, T-2/mon.
MOO - " " " , Oil cos., T-2/mon.
MPRT - Maximum PeRcentage of idle vessels going into Timech.
MPRV - " " " " " " " Voy.ch.
MRT - Maximum Rate of Transfer, T-2/mon.
MRV - " value of RTO, T-2/mon.
MSI - " rate of Scrappage, Independents, T-2/mon.
MSO - " " " " , Oil cos., T-2/mon.
MSP - " " " " , Predicted, " / " .
MULI - MinimUm age Limit on scrappage, Independents, yrs.
MULO - " " " " " , Oil companies, yrs.
NALH - Normal Average Length of Haul, miles
NCDS - " total Construction Delay at Shipyards, mon.
NDI - Negotiation time available for orDering, Indep., mon.
NDO - " " used by Oil companies, mon.
NIFI - Normal Idle Fleet factor, Independents
NMDA - Number of Months Demand is Anticipated, mon.

NRSI - Normal Rate of Scrappage, Indep. (as % of max.)
NRSO - " " " " , Oil cos.,(as % of max.)
NTCO - Negotiation time available to Time Charter,Oil cos., mon.
NXI - Negotiation time actual, Independents, mon.
NXO - " " available to Oil companies, mon.
OPO - Owned tankers, Projected, of Oil companies, T-2s
OTI - " " of Independents, T-2s
OTO - " " " Oil companies, T-2s
OUTP - productivity OUTPut, T-2/man-month
PCD - Projected rate of Change in TDO, T-2/mon./mon.
PCI - " " " " " RTI, " / " / "
PCO - " " " " " RTO, " / " / "
PCS - " " " " " RSO, " / " / "
PDI - Predicted Demand for oil, Independents, bbl/day
PDO - Present Demand for Oil, bbl/day
PDT - " " " Tankers, T-2s
PFI - Predicted Fleet requirements, Indep.,T-2s
PFS - Possible Firing rate, at Shipyards, men/mon.
PHDO - Past History of Demand for Oil (boxcar train)
PHDO*1 - first boxcar in PHDO, bbl/day
PHS - Possible Hiring rate, at Shipyards, men/mon.
PID - Projected average Increase in TDO, T-2/mon.
PII - " " " " RTI, " / "
PIO - " " " " RTO, " / "
PIS - " " " " RSO, " / "
PLDI - Part of oil co. market that is Desired by Indep., at maximum FTP
PNI - Predicted New vessels, Independents, T-2s
POI - " Ownership, Independents, T-2s(revision)
POI - Percentage of total vessels Owned by Indep.(original)
POR - Predicted additional Ownership Requirements, T-2s
PPD1 - " Present Demand, least square method, bbl/day
PPD2 - " " " , smoothing method, bbl/day
PRI - " ownership Requirements, Indep., T-2s
PRO - Percentage of Requirements to be met by Owned vessels
PROT - Tabular value of PRO
PRT - Percentage of Requirements to be met by Time charters plus owned ships
PRTT - Tabular values of PRT
PSD1 - Predicted Slope of Demand, least square method, b/d/mo.
PSD2 - " " " " , smoothing method, bbl/day/m.
PSI - Predicted Scrappage, Independents, T-2s
PSM - Present Share of Market, independents
PTE - Percentage of Tankers Employed
PTR - Predicted additional Time charters Required, T-2s
RDO - artificial rate for extrapolating PDO
RDH - Rate of Demand History accumulation, bbl/day/mon.
RHDO - Recent History of Demand for Oil (boxcar train)
RHDO*1 - first boxcar in RHDO, bbl/day
RHDO*2 - second " " " , " / "
RIS - Smoothed value of RTI, T-2/mon.
ROS - " " " RTO, " / "
ROT - Rate of Oil company vessel Transfer, T-2/mon.
RPD - Ratio of actual to Predicted Demand

RSI - Rate of Scrappage, Independents, T-2/mon.
RSM - Ratio of desired to present Share of Market
RSO - Rate of Scrappage, Oil companies, T-2/mon.
RSP - " " " , Predicted, T-2/mon.
RSPI - " " " , " , Indep.,T-2/mon.
RSS - Smoothed value of RSO, T-2/mon.
RTI - Rate of Time charters going Idle, T-2/mon.
RTO - " " " " " into Operation, T-2/mon.
RVI - " " Voyage charters going Idle, T-2/mon.
RVO - " " " " " into Operation,T-2/mon.
SCC - Shipyard Construction Capability, T-2/mon.
SDO - Smoothed Demand for Oil, bbl/day
SNBS - Size of Normal Backlog at Shipyard, mon.
SOS - Smoothed Order rate at Shipyards, T-2/mon.
SPO - Scrappage, Projected, of Oil companies, T-2s
STIN - Shifting Time INterval, mon.
STO - Share of market that is desired to be Taken Over, at maximum FRP
STR - Second Trial Rate (ROT), T-2/mon.
TAP - Tankers Additionally required to meet Projected demand
TBI - Tanker Backlog at shipyards, Independents, T-2s
TBO - " " " " , Oil companies, T-2s
TBTO - Time Before Time charters go into Operation, mon.
TBVO - " " Voyage " " " " , "
TBX - part of TBI that is expected to be delivered if EDT is greater than NCDS
TCI - Tanker Construction start rate, Indep., T-2/mon.
TCO - " " " " , Oil cos., T-2/mon.
TCT - Total Construction sTart rate, T-2/mon.
TCTC - Time, average, on Charter for Time Charters, mon.
TCVC - " , " , " " " Voyage " , "
TDES - " over which it is desired to Decrease Employment at Shipyards, mon.
TDDO - Time constant in Delay for DDO, mon.
TDI - Tanker Delivery rate to Independents, T-2/mon.
TDO - " " " " Oil companies, " / "
TDS - Smoothed value of TDO, T-2/mon.
TFST - Time period for Fitting a StraighT line to the data, mon.
TIES - Time over which it is desired to Increase Employment at Shipyards, mon.
TIN - Tankers to be ordered by Independents, with Normal freight rate, T-2/mon.
TIRC - Time period for InteRmediate Considerations, mon.
TLTC - " " " Long Term Considerations, mon.
TITI - " " " " " " , Indep.,mon.
TNOO - " Needed to put vessel into Operation, Oil co.,mo.
TNVC - " , average, available to Negotiate for Voy.Ch.,mo.
TOO - Tankers in Operation, oil Companies, T-2s
TOI - Tanker Ordering rate, Independents, T-2/mon.
TOO - " " " , Oil companies, " / "
TOP - Tankers required to be Obtained to meet Projected demand, T-2s
TOT - Tankers On Time charter, T-2s
TOUS - Time period Over which it is desired to correct Unstarted backlog at Shipyards,mon.

TOV - Tankers On Voyage charter, T-2s
TPI - " Projected to go Idle off time charter, T-2s
TPO - " " " " On time charter, T-2s
TPT - " " on Time charter, T-2s
TRO - Trial Rate of Transfer (ROT), T-2/mon.
TSDO - Time period for Smoothing the Demand for Oil, mon.
TSFR - " " " " FRV, mon.
TSOS - " " " " Order rates at Shipyds.,mo.
TSRI - " " " " RTI, mon.
TSRO - " " " " RTO, "
TSRS - " " " " RSO, "
TSTD - " " " " TDO, "
TTI - predicted raTe of Tonnage Increase, T-2/mon.
TUDV - Time period in which it is desired to deplete UDV,mo.
TUI - Tankers Under construction for Independents, T-2s
TUO - " " " " Oil companies, "
UDV - Unfilled Demand for Voyage charters, T-2s
UIS - Unstarted orders, Independents, at Shipyards, T-2s
ULR - Upper Limit of Rate ROT, T-2/mon.
UNS - Unstarted order backlog, Normal, at Shipyards, T-2s
UOI - fraction of total Unstarted backlog ordered by Oil cos.
UOS - Unstarted orders, Oil companies, at Shipyards, T-2s
URV - Unfilled chartering Rate, Voyage, T-2/mon.
XAI - eXcess Age in fleet, Indep.,yrs.
XAO - " " " " , Oil cos.,yrs.
XAP - " " " " , Predicted, yrs.
XPI - eXponential Power for scrappage rate, Independents
XPO - " " " " " , Oil cos,
XPP - " " " " " , Predicted
XPPI - " " " " " , " ,Indep.
XRV - difference between desired and maximum rates, T-2/mon.
YSI - T-2 Years of Scrapped vessels, Indep., T-2-yrs.
YSO - " " " " " , Oil cos.," - "
YUI - " " " Unscrapped " , Indep., " - "
YUO - " " " " " , Oil cos.," - "