A SIMULATION OF AN EXPORT COMMODITY DISTRIBUTION SYSTEM

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ABSTRACT

A stochastic model describes the flow of commodities through a distribution system for export. Primary emphasis is placed on the role of the decision maker (merchandizing manager) of the system, the means of transportation, and the export facility (export elevator). In the model appear submodels of descriptive, heuristic, and normative-analytic types. The output of the model gives all of the relevant costs associated with the system and has implications as to the physical configuration of the export facility.

INTRODUCTION

Currently food prices are rising in the United States, and the government as well as private groups are reviewing the impact of the recent large grain purchases made by the Soviet Union. The simulation model presented in this paper examines the distribution system and its physical components for the export of farm commodities from the point of view of a grain exporting firm. The model concentrates on the role of the decision maker (merchandising manager) and the export facility (elevator). The objective of the model is the determination of operational as well as physical rules for the optimization of the system.

THE PHYSICAL SYSTEM

Physically, the system consists of farms, storage facilities, a transportation network, and an export facility. The system is bounded at one end by the origination of the commodities (the Farm), and at the other end by the loading of ocean-going vessels that will deliver the commodities to foreign purchasers.

Figure 1 represents the actual flow of commodities. After commodities are harvested they may be stored either on the farm or at local storage facilities (elevators).

The classification of elevators in three types, depends on two characteristics--location and function. Country elevators are the smallest, buy primarily from farmers, and typically receive commodities by truck; they ship by truck or railroad. Terminal or sub-terminal elevators are usually located at a central railroad junction or at a location where the mode of transit changes, e.g. from truck or railroad to barge. These elevators buy primarily from dealers.

Agricultural commodities must be stored in elevators to prevent deterioration principally caused by moisture. An elevator consists of large cylindrical storage bins (similar to silos) and a system of conveyor belts. Commodities are brought to the elevator and dumped into a pit--in the case of trucks and railroad. From the pit, conveyor belts carry commodities laterally under the elevator and then to the top where they are dumped into storage bins. In the case of barges, a conveyor is lowered into the barge and the commodity is elevated to the top of the facility and dumped into the bins. Storage bins are constructed so that gravity feed allows the commodities to flow out of the bottom of the bin and onto a conveyor that leads to a loading facility. In the case of local or terminal elevators, the commodities are loaded into barges or railroad cars. From the export elevators, the commodities are loaded aboard ships.

The function of an export elevator is multifold. Besides performing a transfer function, it provides a storage function; a segregation function, (i.e. kind of commodity, class of commodity, and grade of commodity); a blending function; and a buffer function. As a buffer, it provides an expansion tank or reservoir to accommodate receipts in excess of shipments or vice versa.

DECISIONS IN THE SYSTEM

The essential part of the export system consists of the export elevator. The decision-making process concerns the prices at which commodities will be purchased from the interior and sold abroad. These decisions may be characterized as strategic and tactical.

Strategic decisions are concerned with position-taking. The merchandising manager may take a "short" or "long" position on commodities with regard to sales that he has made for future delivery. The position he takes is a function of his estimate of price changes in the interior as well as abroad. Tactical decisions are concerned with having enough of the proper commodities at the export facility for vessels when they arrive (i.e. to avoid out-of-stock costs).

The input to the export elevator (supply), the output (demand), and prices are stochastic. If the system is considered as a physical flow, very little control is held over either the input or output of the export facility.

PURCHASING COMMODITIES

Every day the merchandising manager bids in order to purchase commodities from farmers or interior elevators. Simultaneously, he is making offers to foreign buyers. When purchases are made from the interior, the contract for the commodity specifies an amount of time within which the seller must load the commodity onto some means of transit. The most common purchase contract is for thirty days. For this type of contract, the seller may load the commodity at any time during the thirty days and may divide the sale into as many parcels as he wishes. Similarly, he may ship the total amount of the sale at once. When and how much he ships is also determined by the availability of transit facilities. Other typical contracts are for twenty, forty-five, or sixty-day shipping periods.

There is another important type of contract in which the purchaser specifies the exact period of time within which the quantity must be shipped. Generally this period would not exceed ten days. For this type of contract, a premium is paid to the seller.

SELLING COMMODITIES

The merchandising manager is constantly being contacted by foreign buyers who make offers. Typically there are a number of firms and cooperatives that sell from the same port. The buyer contacts all of them for offers and will buy at the lowest price. The customary size of a sale is in the thousands of tons.

A selling contract is a great deal more intricate than a purchase contract. The terms of the contract specify: (1) a commodity, (2) a grade, (3) a price, (4) a shipping period, and (5) usually the type of vessel. The shipping period specifies two dates within which the buyer's ship must arrive at the export elevator to receive the purchase. The type of vessel is important because it determines the rate at which the commodity can be loaded. Agricultural commodities are transported on three-deck, two-deck, tanker, or bulk carrier ships.

Any deviations from the contract terms are reflected in a renegotiation of the price. In addition, the purchaser must give advance notice of an arriving ship. Generally, a minimum of two weeks notice is required. When a ship enters the harbor it must first be inspected and given approval to carry commodities. The date upon which a vessel presents itself at the elevator, after having passed inspection, is called the "ready date."

A commodity merchandising firm may sell commodities FOB, CIF, or C and F. This means that it may or may not charter vessels and deliver commodities abroad. In this study the assumption is made that all of the vessels that arrive at the export elevator are chartered by the company. This was done in order to assess ship demurrage and despatch as an operating (variable) cost of the system. Another way of examining this assumption is as a quantitative approximation of customer good will.

SYSTEM COSTS

In the system, variable costs are defined as: purchase cost of commodities, carrying cost, ship demurrage/despatch, railroad demurrage, out-of-stock cost, labor cost.

The purchase cost of commodities can be broken into the cost of the various types of contracts. This is done in order to account for premiums that may be paid for short term contracts, i.e. ten days or less. When commodities are owned by a merchandising company, they incur a carrying cost. The carrying cost rate was 8.8% per year, at the time of this study.

Ship demurrage is a cost paid on a daily basis for taking longer than a specified period of time to load a vessel. Ship despatch is a negative cost in that it is an amount paid to the charterer of the ship by the shipowner, on a daily basis, for loading the vessel in less time than the number of loading days specified. The daily rate for despatch is generally one-half the daily demurrage rate.

The out-of-stock cost is the cost of purchasing commodities from a competitor at his export elevator. This cost is the current price of the commodity plus a premium.

Railroad demurrage is a fee paid to the railroad for the use of railcars delivered to the export elevator and not unloaded within a given period of time. After this time, the daily demurrage rate increases as a step function. This cost may be considered expensive temporary storage that is used when the elevator is full.

The labor cost may be divided into regular and overtime wages. The overtime wages can be further classified according to what function in the elevator is being performed. Overtime shifts may be worked: (1) unloading trucks, (2) unloading barges, (3) unloading railcars, and (4) loading ships. Each of these functions may be performed independently in the export elevator.

The fixed costs in the system include such costs as trading and administrative expense, supervisory and clerical expense, insurance, and capital or rental costs.

SYSTEM SIMPLIFICATION

The decision-making process in the system is a feed-back control mechanism. Contingent upon expected or current prices, inventory, and outstanding contracts, decisions concerning sales and purchases over a nearby or longer term period are made. This interaction can be closely approximated without resorting to a feedback control loop. The relative proportions of fixed to variable costs are important. In a system such as this, the fixed costs are an overriding factor, and the amount of profit involved in a sale is low. As a result of these considerations, inventory turnover must be high. It is not uncommon to find a turnover rate of ten to fifteen times the capacity of an export elevator each year. When these points were considered, demand was treated as an exogenous variable in the model, with care given to the pattern and the amount that must be shipped.

Purchase contracts for commodities from the interior are for three, ten, fifteen, thirty, forty-five, and sixty-day periods. The two most important and most frequently used are the thirty-day and ten-day contracts.

When control is exercised to a strong degree over means of transportation bringing commodities to the export elevator, a steady-state input is assumed.

Within the model no record is kept regarding the grades of the various commodities. Commodities are purchased from the interior on the basis of grade one. If the grade is lower, a standard discount price is paid to the seller. When selling commodities abroad, the vast majority of sales is for grades one and two. It is assumed that the export elevator can blend the required grades, given the inventory. Since different grades of the four commodities are kept in inventory, the facility cannot be 100% full at any time because the various grades are segregated in different bins, and it is unlikely that all the bins will be full. A binning efficiency of 80% was selected as reflecting this fact. Therefore, in an export facility that has three million bushels of storage space, only 2.4 million bushels are actually available.

The four commodities in the system are not shipped to the export facility by all modes of transportation. The railroad is the only mode that carries all four. Barges carry commodity one and some amounts of commodity four. Trucks only carry commodity one. In the system, barges account for 30% of all commodities shipped to the export facility, trucks 5%, and railroad the remaining 65%. Because of the small amount contributed by truck, this variable was treated as a constant input because of its controllability. The variability of the input to the elevator lies principally with the railroad. This input is treated as a stochastic variable in the model. On the output side of the export facility, the only mode of transport (ships) is treated as a stochastic variable.

THE MODEL

The total model simulates the operation of the system on a daily basis (Figure 2). This is done through the use of a linear programming model and queuing models. Both of these models have stochastic characteristics. In the model, four commodities are handled simultaneously. Exogenous demand is generated for a one year period of time and fed as input to the model. This input is examined by the model on a weekly basis as simulated time progresses.

Given this demand, each week a linear programming model determines what should be purchased to meet sale committments. It also minimizes the purchase cost of the commodities as well as their carrying costs. The linear program purchases commodities with thirty-day contracts only.

The next part of the model unloads the railroad, truck, and barge queues and brings the appropriate commodities into the export elevator. This is done according to decision rules that determine: (1) what commodities are needed to load the next ships that will arrive; (2) the maximum amount of commodities that may be unloaded by working overtime shifts; (3) what means of transit will be unloaded; and (4) the maximum amount that may be brought into the facility without exceeding its storage capacity.

Next the model handles the queue of ships that arrive at the export elevator. This sub-model is a fixed time queuing model with stochastic service times that are functions of the type of vessel that arrives. Within this part of the model are decision rules that determine: (1) if overtime shifts will be worked to load vessels, (2) whether a ship meets an out-of-stock condition and will be kept another day in hope that the proper commodity and quantity will arrive on the next day, (3) whether an out-of-stock ship should be sent to a competitor's elevator, (4) the amount of ship demurrage/despatch that accrues to each vessel.

Another routine calculates railroad demurrage and will bring into the elevator the commodities in those railcars that are accruing demurrage if there is sufficient storage space available.

The final part of the model consists of an algorithm that is given two weeks notice as to the arrival of the next ship. This routine calculates the expected inventory for the next two weeks and examines the requirements for all the ships that will arrive within this period. If sufficient inventory will not be available, ten-day purchase contracts for the proper commodity are made.

Finally, the model calculates and summarizes all of the costs for the year.

LINEAR PROGRAMMING SUB-MODEL

The linear programming sub-model is used to purchase commodities using thirty-day contracts. It is a highly modified version of the warehouse problem described by A. Charnes and W. W. Cooper (1). It is solely concerned with the purchase of commodities that arrive at the export elevator by railroad. The arrival of railcars at the facility is the least controllable and has the greatest variability of the input means of transport and is described by a probability distribution. The distribution was obtained by analyzing the data for approximately ten thousand railcars. The time horizon of the model is thirteen weeks. The algorithm gives the amounts to be purchased over this period, but since the sub-model is used weekly, the only concern is purchases for the current week. Therefore, the linear program is dynamic over time.

The constraints are of three types: (1) three inequations that do not allow a violation of the storage capacity of the facility, (2) twelve inequations that require demand for the commodities over the various time periods be met (i.e. current week, in four weeks, in eight weeks), (3) four equalities that are inventory balance equations for each commodity over the thirteen-week time horizon. These equalities are necessary to introduce an ending inventory rule. The algorithm is used to minimize the cost of acquiring commodities as well as carrying costs; and would always try to end the thirteen-week period with zero inventory if these constraints were not introduced.

DEFINITIONS OF SYMBOLS USED IN THE LINEAR PROGRAMMING MATRIX

S -Effective storage capacity of export facility

K -Current week

BI_c-Beginning inventory of commodity c

EI_c-Ending inventory of commodity c

D_{ci}-Expected demand in week i of commodity c

R_{ci}-Arrival at the export facility of commodity c in week i by railroad

T_{ci}-Arrival at the export facility of commodity c in week i by truck

B_{ci}-Arrival at the export facility of commodity c in week i by barge

x_1 -amount of commodity 1 to be purchased now

x_2 -amount of commodity 1 to be purchased in four weeks

x_3 -amount of commodity 1 to be purchased in eight weeks

x_4 -amount of commodity 2 to be purchased now

x_5 -amount of commodity 2 to be purchased in four weeks

x_6 -amount of commodity 2 to be purchased in eight weeks

x_7 -amount of commodity 3 to be purchased now

x_8 -amount of commodity 3 to be purchased in four weeks

x_9 -amount of commodity 3 to be purchased in eight weeks

x_{10}-amount of commodity 4 to be purchased now

FIGURE 3. THE LINEAR PROGRAMMING MATRIX

FOR START OF WEEK K

CONSTRAINT	WEEK	x's 1	2	3	4	5	6	7	8	9	10	11	12	
I	K+1	.35			.35			.35			.35			$\leq S - \sum_{c=1}^{4} \left[BI_c - \sum_{i=K+1}^{K+2} (D_{ci} - R_{ci} - T_{ci} - B_{ci}) \right]$
II	K+4	1.	.35		1.	.35		1.	.35		1.	.35		$\leq S - \sum_{c=1}^{4} \left[BI_c - \sum_{i=K+1}^{K+4} (D_{ci} - R_{ci} - T_{ci} - B_{ci}) \right]$
III	K+8	1.	1.	.35	1.	1.	.35	1.	1.	.35	1.	1.	.35	$\leq S - \sum_{c=1}^{4} \left[BI_c - \sum_{i=K+1}^{K+8} (D_{ci} - R_{ci} - T_{ci} - B_{ci}) \right]$
IV	K+1	.35												$\geq \sum_{i=K+1}^{K+2} \left[D_{1i} - R_{1i} - T_{1i} - B_{1i} \right] - BI_1$
V	K+4	1.	.35											$\geq \sum_{i=K+1}^{K+4} \left[D_{1i} - R_{1i} - T_{1i} - B_{1i} \right] - BI_1$
VI	K+8	1.	1.	.35										$\geq \sum_{i=K+1}^{K+8} \left[D_{1i} - R_{1i} - T_{1i} - B_{1i} \right] - BI_1$
VII	K+1				.35									$\geq \sum_{i=K+1}^{K+2} \left[D_{2i} - R_{2i} \right] - BI_2$
VIII	K+4				1.	.35								$\geq \sum_{i=K+1}^{K+4} \left[D_{2i} - R_{2i} \right] - BI_2$
IX	K+8				1.	1.	.35							$\geq \sum_{i=K+1}^{K+8} \left[D_{2i} - R_{2i} \right] - BI_2$
X	K+1							.35						$\geq \sum_{i=K+1}^{K+2} \left[D_{3i} - R_{3i} \right] - BI_3$
XI	K+4							1.	.35					$\geq \sum_{i=K+1}^{K+4} \left[D_{3i} - R_{3i} \right] - BI_3$
XII	K+8							1.	1.	.35				$\geq \sum_{i=K+1}^{K+8} \left[D_{3i} - R_{3i} \right] - BI_3$
XIII	K+1										.35			$\geq \sum_{i=K+1}^{K+2} \left[D_{4i} - R_{4i} - B_{4i} \right] - BI_4$
XIV	K+4										1.	.35		$\geq \sum_{i=K+1}^{K+4} \left[D_{4i} - R_{4i} - B_{4i} \right] - BI_4$
XV	K+8										1.	1.	.36	$\geq \sum_{i=K+1}^{K+8} \left[D_{4i} - R_{4i} - B_{4i} \right] - BI_4$
XVI	K+13	1.	1.	1.										$= EI_1 - BI_1 - \sum_{i=K+1}^{K+13} \left[R_{1i} - B_{1i} - T_{1i} - D_{1i} \right]$
XVII	K+13				1.	1.	1.							$= EI_2 - BI_2 - \sum_{i=K+1}^{K+13} \left[R_{2i} - D_{2i} \right]$
XVIII	K+13							1.	1.	1.				$= EI_3 - BI_3 - \sum_{i=K+1}^{K+13} \left[R_{3i} - D_{3i} \right]$
XIX	K+13										1.	1.	1.	$= EI_4 - BI_4 - \sum_{i=K+1}^{K+13} \left[R_{4i} + B_{4i} - D_{4i} \right]$

x_{11}-amount of commodity 4 to be purchased in four weeks
x_{12}-amount of commodity 4 to be purchased in eight weeks

In the objective function of the first twelve terms consist of the average length of time (over the thirteen-week horizon) that a purchase would be kept in the facility, multiplied by the holding cost of the commodity.

$$Z = .0169\ (10.9x_1P_{1,1} + 7.9x_2P_{1,4} + 3.9x_3P_{1,8} + 10.9x_4P_{2,1} + 7.9x_5P_{2,4} + 3.9x_6P_{2,8} + 10.9x_7P_{3,1} + 7.9x_8P_{3,4} + 3.9x_9P_{3,8} + 10.9x_{10}P_{4,1} + 7.9x_{11}P_{4,4} + 3.9x_{12}P_{4,8})$$

Where $P_{i,j}$ = the price in week j for commodity i.

Prices for the four commodities are generated in the model. An analysis of the prices of the four commodities showed: (1) there was a pronounced seasonality factor over the long run, (2) prices of commodities delivered to the export elevator are lowest around harvest time, (3) after harvest, prices rise fairly rapidly until the beginning of winter and then tend to remain steady, (4) prices start to fall rapidly just prior to the harvest.

From the analysis, it was concluded that a sinusoid type curve would best duplicate this behavior. It also appeared that about 80% of the time this pattern held on a week-to-week basis, but 20% of the time the anticipated direction of price changes was reversed, so a random factor was introduced.

RESULTS

The model was built with two goals in mind. The first goal was to determine operational rules for the optimization of the system. The second goal pertains to changes in the physical rules of the system.

In the construction of the simulation model, a multi-stage verification methodology (2) was used. The first stage consisted of attempting to find the underlying behavioral rules of the system. After these were understood, by means of personal observation and the questioning of practitioners of commodity merchandising, the basic framework of the model was formed.

It would be virtually impossible to empirically test all of the underlying assumptions of the model, since interactions do occur. Therefore, empirical testing was performed on the model after it had been initially run on the computer. At this point, certain assumptions in the model had to be adjusted until the empirical evidence embodied in the results conformed more to the actual operating characteristics and costs of a real export elevator. At the current stage, the model complies with Friedman's positive economic approach in that the model may be used to predict the behavior of the system. The results of the model have been discussed with individuals involved in commodity merchandising and they seem "reasonable." This was the final test for the validation of the model.

In order to test the stability of the system, ten runs were made. Each run used a different starting point in the sequence of random numbers--all other parameters, data prices, and decision rules were the same. The results, in terms of total costs for each run, are given in Table 1.

The arithmetic mean of the ten runs is 46.49 million dollars. The standard deviation is .10 million dollars. The range of the observations is from 46.30 to 46.61 million dollars -- .31 million dollars. The system appears to be very stable.

Table 2 lists the results of these runs for each cost component of the total cost over the ten runs, as well as the result for two non-cost parameters of the system. These parameters are the days the elevator is full (ICLOG), and the number of overtime shifts worked for loading ships.

Almost all of the component costs show stability in that there is very little deviation considering their magnitude. The only cost that seems to fluctuate greatly is the out-of-stock cost. The maximum fluctuation appears in run ten. The total out-of-stock cost in this run is $31,000. When this is compared with other runs it may appear to be extra high, but one must keep in mind that the $31,000 out-of-stock cost was incurred because of an out-of-stock condition for approximately 500 tons of a commodity for one ship. During the year, almost 1.2 million tons were shipped and 125 ships were loaded. When one compares the out-of-stock cost to these figures, the fluctuations become insignificant.

The next series of computer runs deal with determining the optimal ending inventory rule for the thirteen-week purchasing horizon. When the model is run, the ending inventory may be fixed at any value in the linear program--from 0% to 100% of effective capacity. Table 3 indicates the results of these runs.

TABLE 1

RESULTS OF COMPUTER RUNS FOR MODEL STABILITY (IN MILLION DOLLARS)

Run	Total Cost
1	46.61
2	46.55
3	46.40
4	46.52
5	46.58
6	46.61
7	46.30
8	46.44
9	46.37
10	46.52

TABLE 2

COST COMPONENTS FOR TEN RUNS

	TOTAL OUT OF STOCK COST	SHIP DEMURRAGE	SHIP DESPATCH	RAILROAD DEMURRAGE	INVENTORY CARRYING COST	LABOR COST	OVERTIME RAILROAD UNLOADING COST	OVERTIME BARGE UNLOADING COST	ICLOG	OVERLOAD LOADING SHIPS
Run	Dollars (1000s)	Dollars (1000s)	Dollars (1000s)	Dollars (1000s)	Dollars (1000s)	Dollars (1000s)	Dollars	Dollars	Days	Days
1	0	57.0	205.5	22.7	266	17 .3	1550	2750	20	38
2	0	49.5	198.0	26.4	275	178.1	2480	2750	25	38
3	3.16	54.0	189.0	21.7	273	176.5	3100	3000	22	33
4	0	46.5	195.8	22.2	275	176.3	2480	2750	24	32
5	0	49.5	200.2	24.3	276	176.2	3410	2750	24	32
6	0	60.0	205.5	22.6	268	174.2	1860	2750	22	28
7	0	49.5	200.3	25.1	276	177.7	2790	2750	23	36
8	7.09	52.5	197.2	24.7	273	177.0	2480	2750	24	32
9	0	49.5	202.5	21.6	274	179.7	2170	3000	25	35
10	30.98	51.0	198.0	23.5	276	177.5	2790	3000	23	32

TABLE 3

RESULTS OF VARIABLE ENDING INVENTORY RULE

Ending Inventory Rule (% of Capacity)	Total Cost (Million Dollars)	Inventory Carrying Cost (Thousand Dollars)	ICLOG (Days)
0%	46.80	238	16
25%	47.18	259	18
50%	46.58	270	23
75%	46.53	289	29
100%	46.63	304	41

TABLE 4

SHIP DESPATCH/DEMURRAGE
(IN THOUSAND DOLLARS)

KDEX	1		2		3	
RUN	1	2	1	2	1	2
DESPATCH	129	115	198	178	205	198
DEMURRAGE	303	297	102	90	57	50
DESPATCH -DEMURRAGE	-274	-182	96	88	148	148
AVERAGE	-228		92		148	

The only conclusion that may be reached is that the optimal inventory lies between 50% and 100% of capacity. As one would intuitively suspect, both the inventory carrying cost and the number of days the elevator was full (ICLOG) rise as the percentage of capacity rises.

Three different ship-loading facilities were used in the model. The three loading facilities vary as to maximum loading speed. The first can load a vessel at 1,800 tons/hour; the second at 2,660 tons/hour; the third at 3,000 tons/hour. These are indicated by KDEX equal to one, two, or three, respectively. The loading rate, given a value of KDEX, is a function of the ship type-bulk carrier, tanker, two-decker, three-decker. For each type of vessel there is a probability distribution associated with a given loading facility. Table 4 indicates various characteristics associated with the different ship-loading facilities.

The total costs for the 2,660 and 3,000 ton/hour facilities vary slightly, but ship despatch/demurrage and the ship loading frequency vary as would be expected. On the basis of total cost, despatch/demurrage, and the ship loading frequency, the 1,800 ton/hour facility would be eliminated. Ship owners and ship charterers do not like to send vessels to export elevators that are known to be slow in loading vessels. This would affect the elevator in terms of fewer F.O.B. sales and higher demurrage rates in chartering vessels to be loaded at the elevator. The 2,660 ton/hour facility would be acceptable, but the 3,000 ton/hour facility is the best. The marginal construction costs involved in building a 3,000 as opposed to a 2,660 ton/hour facility would be more than offset by the despatch/demurrage savings over a period of a few years.

The model can be considered as a strict physical flow model if prices are held constant over time. The value of this type of analysis is high when one is not certain whether the capacity of the elevator is too small to handle the annual volume. The results of these runs show that on the basis of physical flow, the elevator capacity is sufficient to handle the yearly volume. None of the operating costs are very different from the variable price runs. The ratio of thirty-day to ten-day commodity purchases was the same. Also, there were no out-of-stock conditions.

If the volume were more than the elevator could handle, in the physical flow model certain costs and measures of efficiency would reach very high values (e.g., out-of-stock cost, number of days clogged). This was not the case for these runs. The essential difference between the physical flow (constant price) and variable price models is that the former tends to even the flow of commodities to the elevator. This is demonstrated most clearly in the case of railroad demurrage and days the elevator is full (ICLOG).

CONCLUSIONS

In the simulation model, since all of the analytic, descriptive, and heuristic models are interfaced, and all of the relevant system costs are considered, the problem of suboptimization due to the use of individual models is not present.

Owing to the nature of this simulation model, it is apparent that optimization is approached by parametric ranging. The cost for each computer "run" is approximately $100 at current commercial rates using an IBM 360/65 with 134K. The approximate capital cost of an export elevator of the type considered here is $10,000,000.

The results indicate:
(1) The system is very stable.
(2) The optimal ending inventory lies between 50% and 100% of capacity.
(3) The optimal shiploading facility operates at 3,000 tons/hour.
(4) The capacity of the elevator is quite sufficient to handle the yearly volume.

As was indicated previously, many more operational as well as physical rules may be altered in the model. The above results are presented as being important and representative of the variety of information that may be obtained from the model.

It is possible to invest a great deal of time in exploring the effects of changes in the operational and physical rules of the system. The results illustrate the range of questions that can be answered by the simulation model. To indicate the breadth of the model, additional questions that may be asked regarding the system are as follows:

Physical Rules:
What is the effect on the system
(1) if faster unloading facilities are used
(2) of using only large railroad hopper cars
(3) of shipping trends (i.e., the shift towards the large bulk carrier)
(4) of changing the input transportation mix

Operating Rules:
What is the effect on the system
(1) if fewer commodities are sold
(2) if the sales volume changes
(3) if the inventory carrying rate changes
(4) if no overtime shifts are worked

Given just these sample questions plus the results presented, all forms of combinations of the questions can be asked.

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FIGURE 1. THE PHYSICAL SYSTEM

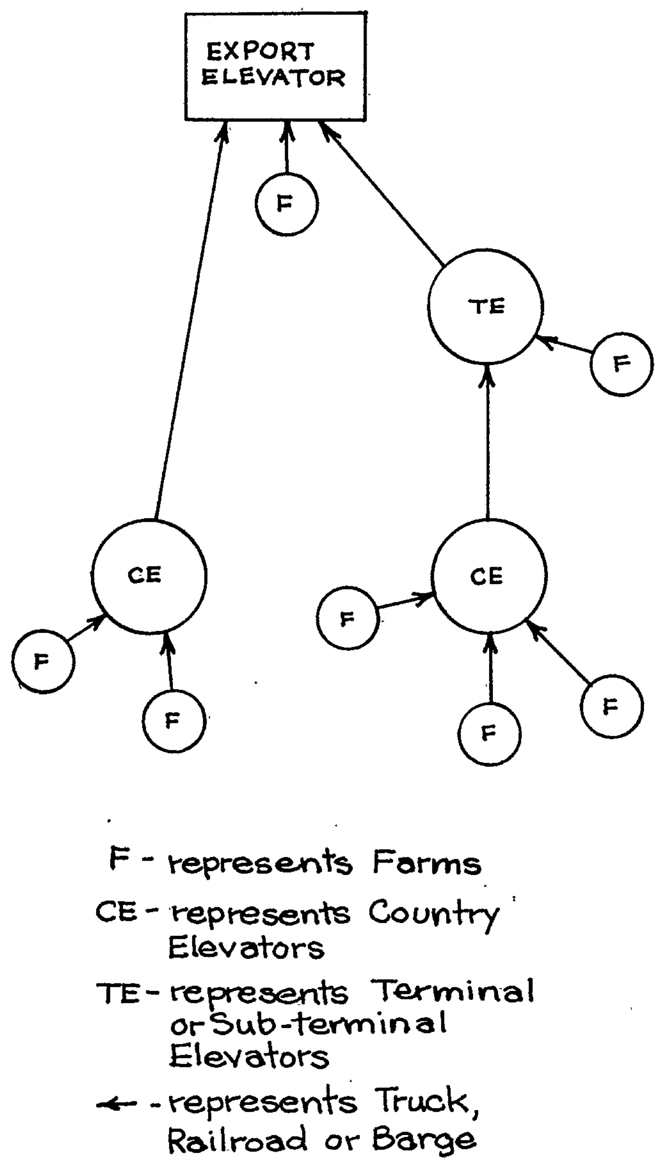

FIGURE 2. FLOW CHART OF MODEL