A Multi-Echelon Production-Distribution System Design for the Petroleum Industry with a Simulation-Analytical Model*

Kee Young Kim**

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INTRODUCTION

Recently one of management's primary concerns has been to develop better production systems, capable of providing swift customer service at low cost. Production-distribution involves a complex set of activities, including production, transportation, inventory, warehouse operations, order processing, and material handling,all of which are regarded as components of single performance system. The structure of the system is determined by the number, size, and location of warehouse facilities that serve as nodal points in the integration of the above components. There have been difficulties in finding the optimum number, size and location of field warehouses all together at a time because most of the models developed have been of a discrete location warehousing network, rather than a total system.

The general motivation of this study was to accomplish the full integration of spatial and temporal relationships in a multi-echelon multi-channel production-distribution system design and incorporation of sufficient realism into the simulation model to evaluate the impact of operational dynamics upon the short-and long-run design. A simulation model was developed in connection with two analytical models for this purpose.

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** Associate Professor of Management, Yonsei University, Seoul, Korea.

THE STATEMENT OF PROBLEMS

The specific problems dealt with in this study may be stated as:

1. Given several sources of production with fixed locations, the capacities of these sources are known, which sources should supply warehouses or customers?

2. Given the geographical location of each customer for which the demand requirements are known and forecasted, how many distribution warehouses should be used, where should they be placed, how large should the capacity of each be?

3. Given a set of operating costs for different modes of transportation, what mode(s) should be employed for the shipments associated with the production source-warehouse-customer configurations?

4. How can the entire distribution function be best organized so that the entire market area can be served at a minimum cost of transportation and at a maximum customer service performance level?

The models developed in the study have been empirically implemented to analyze the characteristics of the existing production-distribution system of a petroleum refiner and distributor in Korea, the Korea Oil Corporation, and improve the design and operation of that system, and changes that would recognize the dynamic interrelationships of a total distribution system.

THE DISTRIBUTION MODEL CONSTRUCTION

The major considerations in the design of the distribution system were 1) the definition of the interconnected sectors within the total system, between which the product and information flows as system variables are taken into consideration, 2) the identifications of the end customer or demand analysis unit with which the production activity is to link and 3) the relationship of the system with the other systems which in this study was taken as the practice of the product exchange with the competing system.

The Echelons of the Distribution System

The production-distribution system was divided into three interconnected echelons. The first echelon comprises sources (refineries) with its adjacent storage tanks; the second echelon is composed of the field bulk terminals (warehouse or mixing points), each of which may stock a variety of inventory assortments; the third echelon is composed of two different types of customers; (a) big customers, mostly industrial firms, some of which are supplied directly from refineries either the company's or the competitors and the rest of which are supplied indirectly through the terminals and (b) agent dealers who are shipping products from their own storages to subdealers and gas stations. All of the big customers and the agents are viewed as end users in this study. The components of each of the three echelons become inventory points within the distribution system.

Demand Analysis Areas as Customer

The georeference system adopted for this study is based on the identification of "demand areas" that serve as proxies for the final customers. These areas are chosen on the assumption that they are the major cities of the nation, the demographic and cultural characteristics of which are representative of the areas to which each is assigned. They are assumes to be used as billing points and basing points for the posted prices of the products.

Product and Information Flow

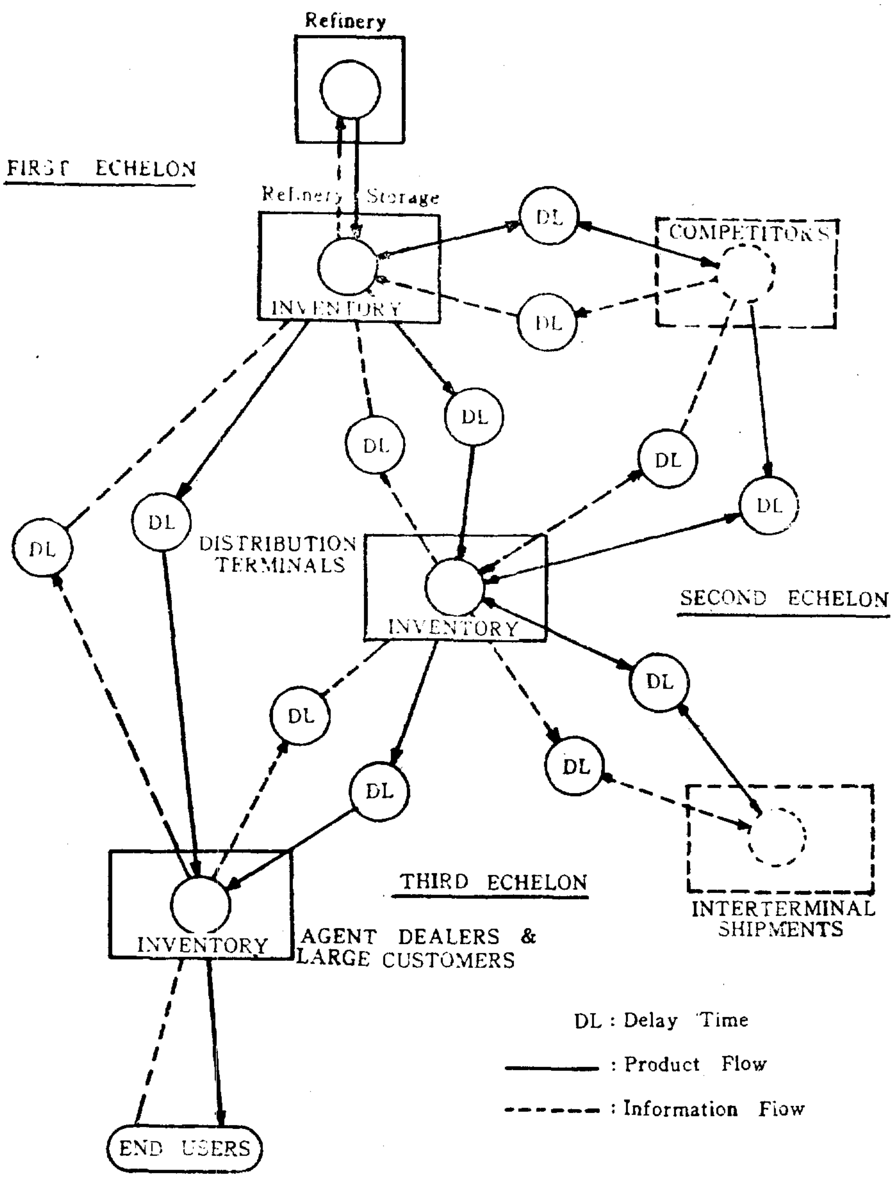
Linkage between and within three echelons can be defined in terms of product and Information Flows. The system structure of the model allows simulation of product and information flow to occur in multichanneled pattern. Interrelationships among the three echelons with respects to product and information flow, and inventory as level variable are diagrammed in Figure 1.

Product Exchanges with Competitors

Product exchanges are assumed to occur in order for one company to supply products at a cheaper distribution cost.

Shipments of products to areas where these now is no nearby terminal owned by company A could be made by drawing the products from an adjacent competitors' terminals. Company A would pay back its competitors

Figure 1. Organization of A Production-Distribution System with Three Echelons



by effecting like transfers, giving them as many barrels as company A owed at some other geographical location.

METHODOLOGY-THREE MODEL APROACH

A simulation model and two analytical models were developed to evaluate the existing distribution system and to test the effects of hypothetical alternative systems in comparison with the existing one. The main simulation model was employed as the basis for the final solution using as part of its input the pilot solutions obtained by the preliminary experiments based on the two analytical models the Terminal Location Model and Inventory Replenishment Model.

As for the preliminary experimental solutions the Terminal Location Model determines the number and location of the terminal network thereby generating assignment of customer (areas) to terminals. Based on the customer-Terminal assignments obtained by the Terminal Location Model. The Inventory Replenishment Model fixes reorderpoint, order quantity, maximum requirement for the fixed replenishment and order view cycle and the parameters of product demands at the preliminary locations.

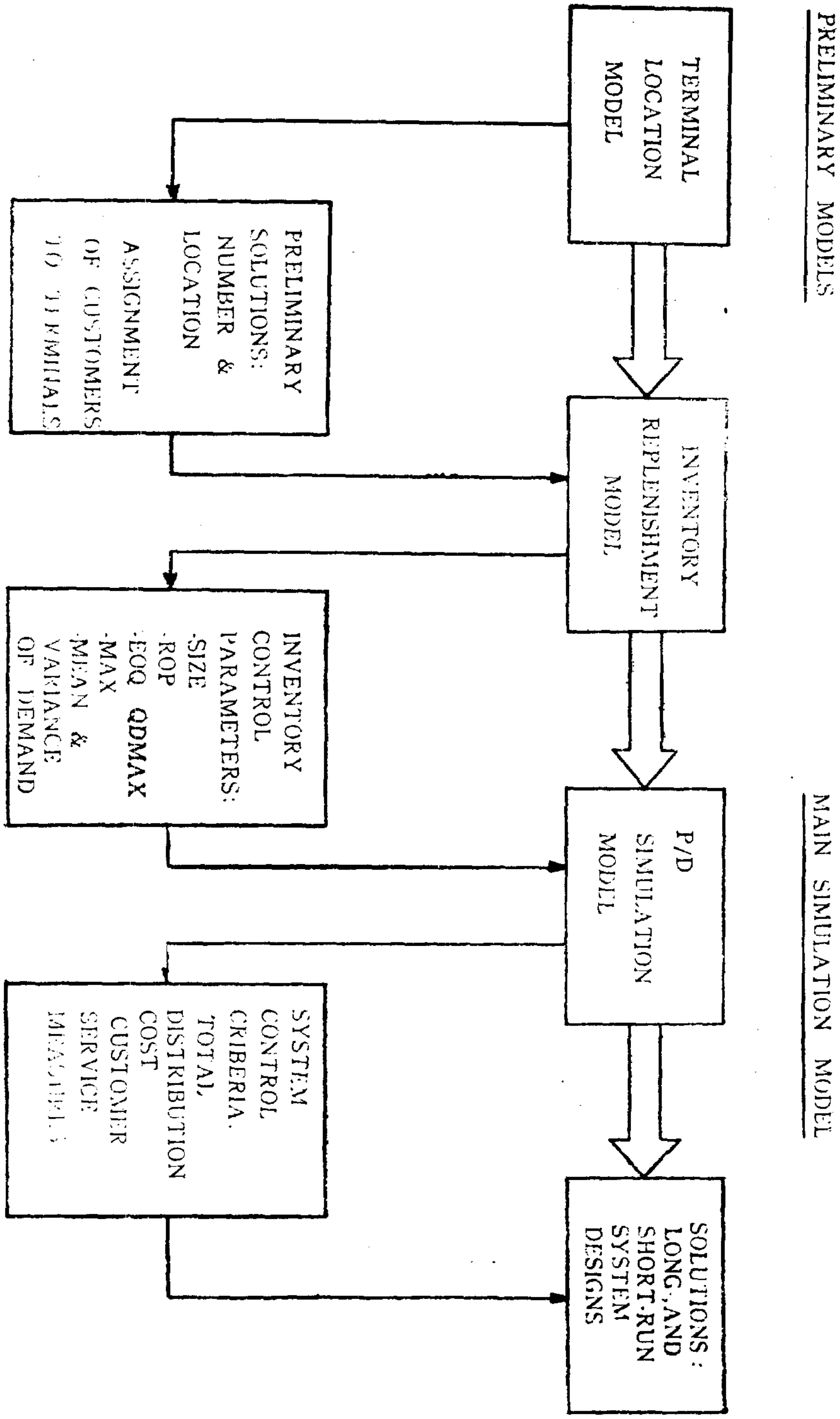
The main Production-Distribution Simulation Model (PDSIM) in turn operates to evaluate and test the hypothetical systems using the terminal control parameters obtained by the Inventory Replenishment Model and he generated daily demand by area.

The PDSIM revises the customer-terminal assignment obtained by the analytical preliminary models through its simulation operations based on the heuristic terminal search processes of the customer areas, thereby redetermining the size of each terminals and inventory control parameters necessary for the terminal operations. The general organization of the three model approache is shown in Figure 2.

Terminal Location Model

Given K customer areas, from which the quantity of demand for each type of product is known (i.e., can be forecasted), and the location of R, refining facilities for which the production capacity is known and which exceeds the total demands of customers, the problem is to locate the sites for terminals that will minimize the combined costs of transferring,

Figure 2. A Brief Organization of Three Model Approach



storing, and distributing the total quantity of petroleum products demanded in the customer areas. The number of terminals, consequently, will also be determined in this process.

An iterative procedure was applied to an initital selection of a set of j field terminals to find the lowest cost combination from that set of possible terminals, even though the combination identified may not be optimal with respect to all criteria.1) The possible number of terminals was reduced one by one in successive trials until a minimum cost combination was reached. The results of these analyses identified the best assignment of customer demand to the terminal locations selected based on minimum total transportation cost. These results of j different possibilities, along with the demand by areas, were used as input into an inventory system model, as the second step of the process, to determine the storage capacity required at each terminal.

The function of the terminal location model is to minimize total transportation and storage cost. This can be stated mathematically as follows:

$$\text{Minimze } TDC = TSC|J + \overline{TTC}|J \quad \text{for } J = 1, 2, \cdots, L \qquad (1)$$

and

$$\overline{TTC}|\mathrm{J} = \underset{LJ}{\mathrm{Min.}}\ (X_K')\bar{C}_j K|L_J \qquad (2)$$

$$TSC|\mathrm{J} = \sum_j S_{j*}\ X_j \qquad (3)$$

$$X_j \geq 0, \quad \sum_j \sum_i X_{ij} = X_j$$

where TDC = total (annual) transportation and storage costs,

$\overline{TTC}|J$ = total transportation cost minimized with respect to terminal location for each value of $J = 1, \cdots L$.

(X_k') = a $(1 \times k)$ vector whose entries, X_k, represent the quantities of product demanded at each of the K demanding areas.

$\bar{C}_{jk}|L_j$ = a vector whose entries, C_{jk}, represent minimized transportation cost between each demanding area K and a specified set of locations, L_J, for J terminals.

C_{jk} = unit cost of shipping products from area K to terminal j. These are defined as $C_{jk} = a_{ij} + b_{jk}$, where a_{ij} is the

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1) **Since these solutions serve only as pilot solutions for testing in the final simulation model, the analysis in the pilot stage considered only transport and storage cost, neglecting other factors.**

minimum transportation cost from refinery i to terminal j while b_{jk} stands for the transport cost between terminal i and customer k.

$TSC|J$=total (annual) storage costs for a set of J terminals

S_{j*}=unit storage cost for the size of terminal j, $j*$ for each value of J.

X_j=quantity of products passing through terminal j, measured in barrels per year.

L_J=one set of J terminals, given L possible locations.

Inventory Replenishment Model

This experimental model is required to fix the size of each terminal based on an inventory replenishment rule incorporating the main decision variables, such as quantity to order, reorder point and safety stock level. The major input data this model needs are the pilot location solutions and the assignment of consuming areas to those terminals, obtained from the procedure described above.

In this study the fixed order interval system(FOI) is employed to determine the decision variables(P. Niland, 1970). In the FOI system, the order quantity is allowed to vary from cycle to cycle (which is fixed in duration) in the amount necessary to absorb random variations in demand. At each ordering date, this order quantity is set equal to an amount necessary to bring stocks up to a level, called "MAX". In this study MAX is set equal to the maximum demand expected over the combined duration of one order review interval and the transportation lead time. The ordering amount is determined by subtracting from MAX the balance on hand and any stock on order, and adding any quantity backordered. Algebraically,

$$Q_{max}=MAX-I-O+B \qquad (4)$$

where Q_{max}=actual order quantity, in barrels,

MAX=maximum number of units required during the replenishment reorder cycle, in barrels.

I=stock level on hand, in barrels.

O=quantity due in from orders placed earlier.

B=quantity due out for backorders.

The value of MAX can be determined for each terminal by using the following formula:

$$MAX = \bar{X}(t_R + \bar{t}_L) + Z\sigma_V \qquad (5)$$

where X = mean daily demand,

t_R = order review internval,

$\bar{t}_L$ = average shipping lead time,

Z = desired confidence level for not being out of stock, expressed as a multiple of the standard deviation of demand,

σ_V = standard deviation of demand during a time period equal to the sum of t_R and t_L (Fetter and Dalleck, 1961).

Algebraically the required size of a terminal may be stated follows:

$$SIZE = \bar{Q}_{max} + 2Z\sigma_V \qquad (6)$$

where $\bar{Q}_{max}$ is average order size and the safety stock term, 2, is provided to recognize the responsibility of a buildup of stock which may be caused by a large negative deviation from the demand.

Pilot Solution of Number and locations of erminals

Total storage costs of the terminals (TSC) now can be calculated, based on their capacities as determined by the preceeding procedure. Once the total storage costs for several values of J (the permissible number of terminals) have been calculated, the total annual transportation and storage costs (TDC) can be obtained by simply summing these costs and the transportation costs $\overline{TTC}|J$, determined earlier by using formula (2). The total costs were determined for different numbers of potential terminal sites and these results were used in selecting the particular terminal networks that appeared to be the most attractive for testing more rigorously with the simulation model.

THE PRODUCTION-DISTRIBUTION SIMULATION MODEL

The main simulation model was used to evaluate both the existing distribution system and hypothetical alternative systems using the pilot solutions developed by employing the two simplified analytical models. The results from the simulation runs for the hypothetical alternative systems were evaluated with respect to two criteria: (1) total distribution costs, and (2) customer service level. Total distribution costs refer to the sum of inbound and outbound transportation cost; all terminaling costs, either fixed or variable, and including inventory carrying cost; depletion costs, representing backordering and lost sales costs; and net location differential costs incurred in effecting product exchanges with other refining companies.

The customer service level is measured in terms of the total number of product stockouts; the number of orders transferred from the normal source to other sources for delivery; total quantity of product backordered; the average duration of the customer order cycle time (which is assumed to be the sum of order communication time); and the total quantity of product which is not supplied by the nearest terminal for customers.

Mathematical Formulation of the Simulation Model

The problem can be mathematically formulated for the simulation model as one of minimizing total distribution costs, which is one of two system decision criteria. The customer service performance, however, can not be included in this mathematical formulation. An objective function can be stated as:

$$\text{Minimize}\quad Z=TTC+TSC+TBC+TFC+TLC \tag{7}$$

$$\begin{aligned}TTC=\sum_t\sum_p\Big[&\sum_i\sum_j T_{pij}X_{pijt}+\sum_j\sum_k T_{pjk}X_{pjkt}+\sum_u\sum_k T_{puk}X_{pukt}\\&+\sum_i\sum_k T_{pik}X_{pikt}+\sum_u\sum_j T_{puj}X_{pujt}+\sum_j\sum_{j*}T_{pjj*}X_{pjj*t}\Big]\end{aligned} \tag{8}$$

$$\begin{aligned}TSC=\sum_t\sum_p\Big[&\sum_j S_{pj}\Big(\sum_{j*}X_{pij*t}+\sum_k X_{pjkt}+\sum_f X_{pjht}\Big)\\&+\sum_i S_{pi}\Big(\sum_j X_{pijt}+\sum_k X_{pikt}+\sum_f X_{piht}\Big)\\&+\sum_j S_{pj*}\Big(\sum_k X_{pjk}\Big)+\sum_i k_{pit}+\sum_j k_{pjt}\Big]\end{aligned} \tag{9}$$

$$TBC=\sum_t\sum_p\sum_k B_{pkt} \tag{10}$$

$$TFC=\sum_p\sum_j F_{pj}Y_{pj}+\sum_p\sum_i F_{pi}Y_{pi} \tag{11}$$

$$\begin{aligned}TLC=\sum_p\sum_t\Big[&\sum_i\sum_u L_{piu}\Big(\sum_k X_{pukt}+\sum_j X_{pujt}\Big)+\sum_u W_{pu}\Big(\sum_k X_{pukt}+\sum_j X_{pujt}\\&+\sum_k X_{pikt}\Big)-\sum_i\sum_j L_{pij}\Big(\sum_f X_{pjft}\Big)-\sum_j W_{pj}\Big(\sum_f X_{pjft}\Big)\\&-\sum_i W_{pi}\Big(\sum_f X_{pift}\Big)\Big]\end{aligned} \tag{12}$$

where:

TTC = total transportation costs for the entire simulation period and

X_{pijt}=amount of product $p(p=1, \cdots p)$ shipped from refinery i $(i-1, \cdots I)$ to terminal $j(j=1, \cdots, J)$ in time period t $(t=1, \cdots, T)$,

X_{pjkt}=amount of product p shipped from terminal j to customer $k(k=1, \cdots, k)$ in time t.

X_{pikt}=amount of product p shipped from refinery i to customer k in time t,

X_{pukt}=amount of product p shipped from KOCO's friend company's terminal $u(u=1, \cdots u)$ to customer k in time t,

X_{pujt}=amount of product p shipped from terminal u to terminal j in time t,

X_{pjj*t}=amount of product p shipped from terminal j to terminal $j^*(j \neq j^*)$ in time t,

T_{pij}=unit transportation cost per barrel of shipping product p from refinery i to terminal j,

T_{pjk}=unit transportation cost per barrel of shipping product p from terminal j to customer k,

T_{pik}=unit transportation cost per barrel of shipping product p from refinery i to customer k,

T_{puk}=unit transportation cost per barrel of shipping product p from terminal u to customer k,

T_{puj}=unit transportation cost per barrel of shipping product p from terminal u to terminal j,

T_{pjj*}=unit transportation cost per barrel of shipping product p from terminal j to terminal j^*.

TSC : Total storage, handling and carrying costs for the entire simulation period and

S_{pj}=variable unit storage and handling cost per barrel of product p at terminal j,

S_{pi}=variable unit storage and handling cost per barrel of product p at refinery storage facility i,

S^*_{pj}=total unit storage and handling cost per barrel of product p at the leased terminal j,

K_{pit}=total inventory carrying cost of product p at refinery storage facility and in transit stocks from refinery i to terminals and customers in time t,

K_{pjt}=total inventory carrying cost of product p at terminal j

and stock en route to customers from terminal j in time t.[2]

TBC : Total backordering and penalty costs for the entire simulation period and

B_{pkt}=total backordering and penalty costs for the amount of product p for customer k in time t.

TFC : Total fixed storage and handling costs for the simulation period and

F_{pj}=fixed cost of operating terminal j for product p over simulation period,

F_{pj}=fixed cost of operating refinery i for product p over simulation period,

Y_{pj}=1 if terminal j of prodnct p is utilized, 0, otherwise,

Y_{pi}=1 if refinery storage facility for product p is utilized, 0, otherwise.

TLC : Total net location differential costs due to the product exchange, and

L_{piu}=unit transportation cost per barrel of shipping product p from refinery i to terminal u, for location differential,

L_{pij}=unit transportation cost per barrel of shipping product p from refinery i to terminal j for location differential,

W_{pu}=unit total storage and handling cost per barrel of product p exchanged at terminal u,

W_{pj}=unit total storage and handlng cost per barrel of product p exchanged at terminal j,

W_{pi}=unit total storage and handling cost per barrel of product p exchanged at refinery i,

X_{pjft}=amount of product p shipped from terminal j to friend company $f(f=1, \cdots, F)$ in time t,

X_{pift}=amount of product p shipped from refinery i to friend company f in time t.

Subject to constraints of the form:

$PRD_{pit} \leq CAP_{pi}$ over all p and i (13)

(Production can not exceed plant capacity).

$IW_{pjt} \leq CW_{pj}$ over all p and j (14)

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[2] For the detailed description, see "Inventory Holding Cost" Under "Cost Functions" in this paper.

(terminal inventory capacity can not be exceeded).

$$IR_{pit} \leq CR_{pi} \text{ over all } p \text{ and } i \qquad (15)$$

(refinery inventory capacity can not be exceeded).

Customer *k's* demand for product p at time t can be defined as:

$$Q_{pkt} = \sum_{i} X_{pikt} + \sum_{j} X_{pjkt} + \sum_{u} X_{pukt} \qquad (16)$$

The ending inventory levels for refinery storage tank and terminals at time t can be defined as follows:

$$IR_{pjt} = IR_{pit-1} + PRD_{pit} - \sum_{j} X_{pijt} - \sum_{k} X_{pift} - \sum_{f} X_{pift} \qquad (17)$$

$$IW_{pjt} = IW_{pjt-1} + \sum_{i} X_{pijt} + \sum_{u} X_{pujt} - \sum_{k} X_{pjkt}$$
$$- \sum_{f} X_{pjft} + \sum_{j*} X_{pj*jt} - \sum_{j*} X_{pjj*t} \qquad (18)$$

The amount of product to be exchanged in time t will be defined by the following equations:

$$PEB_{pft} = \mathrm{PEB}_{pkt-1} + \mathrm{PEC}_{pft} - \Big(\sum_{j} X_{pijt} + \sum_{j} X_{pujt}$$
$$+ \sum_{k} S_{pikt} + \sum_{k} X_{pukt}\Big) \qquad (19)$$

$$PEF_{pft} = PEF_{pft-1} + PEC_{pft} - \Big(\sum_{f} X_{pift} + \sum_{f} X_{pjft}\Big) \qquad (20)$$

with all product flows defined as being zero or positive.

Where:

PRD_{pit}=production of product p at refinery in time period t,

CAP_{pi}=production capacity for product p at refinery i,

IW_{pjt}=inventory level of product p at terminal j at time t,

CW_{pj}=storage capacity for product p at terminal j,

IR_{pit}=inventory level of product p at storage tank of refinery i,

CR_{pi}=storage capacity for product p at storage tank of refinery i,

Q_{pkt}=demand of customer k for product p in time t,

PEB_{pft}=amount of product p in balance to be drawn from company *f's* stock at time t,

PEC_{pft}=contracted amount of product p to be exchanged between KOCO and company f in time t,

PEF_{pft}=amount of product p in balance to be drawn from KOCO's terminals or refinery to the company f in time t.

where every subscript t means "in time period t." The simulation model is designed to run with the length of the time period being one day.

Programming and Running the PDSIM Model

The main PDSIM model was programmed in PL/I and run through IBM 360/65 PL/I (F) compiler. The compiling of the program (no· data) required 1.23 CPU minutes. Storage capacity requirement for the program and its input data for 20 terminal system, was 230*k*. A summary flowchart of the Simulation Model's system flow is provided in Figure 3. The basic operations for the system may be described as follows: Having specified the basic system variables the simulation model starts to run by reading the input data from the data files. Daily orders by customer by product are generated by Monte Carlo simulator for each day of the simulation period designated for the runs.

The system runs based on each product until it exhaustes the product loop. Inside the product loop, time loop, and customer loop are nested in order. Before processing each customer the backorders are filled and backordering costs are computed.

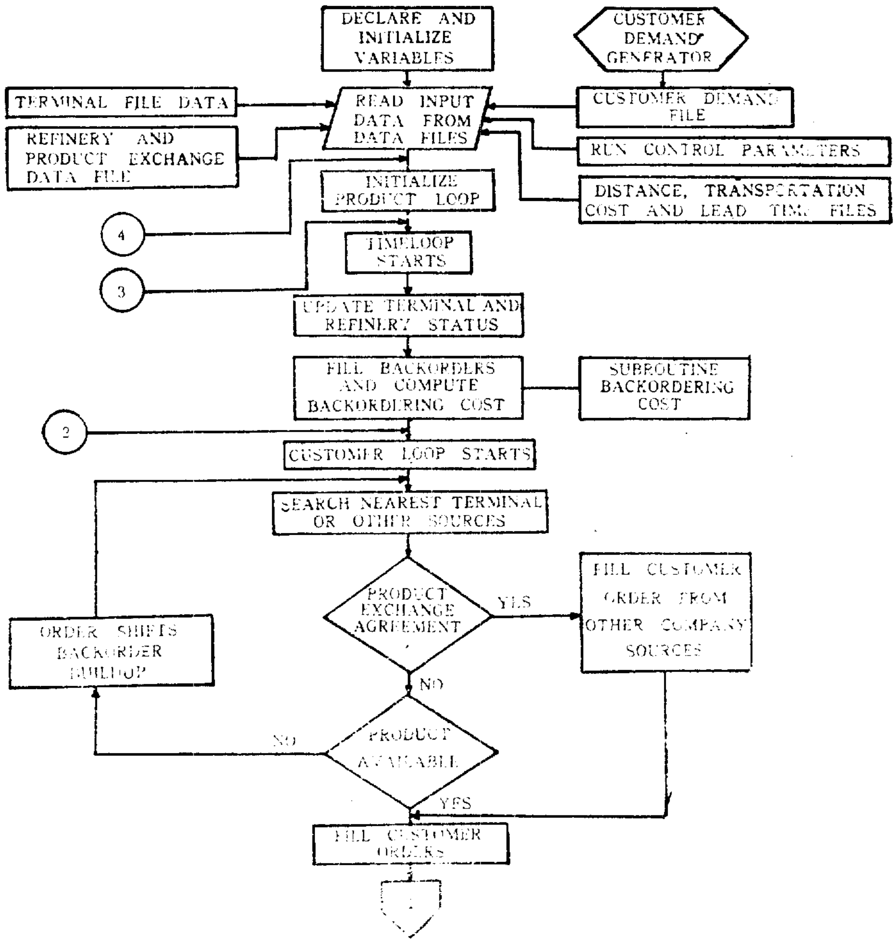
Terminal searches are heuristically made for each customer location regarding with the availability of stock on hand and product exchange balance based on which order shifts or/and backorders would be built up. The variable storage and transportation costs for customer-terminal transactions are computed on the basis of transportion modes available for the deliveries and order cycle time is simulated.

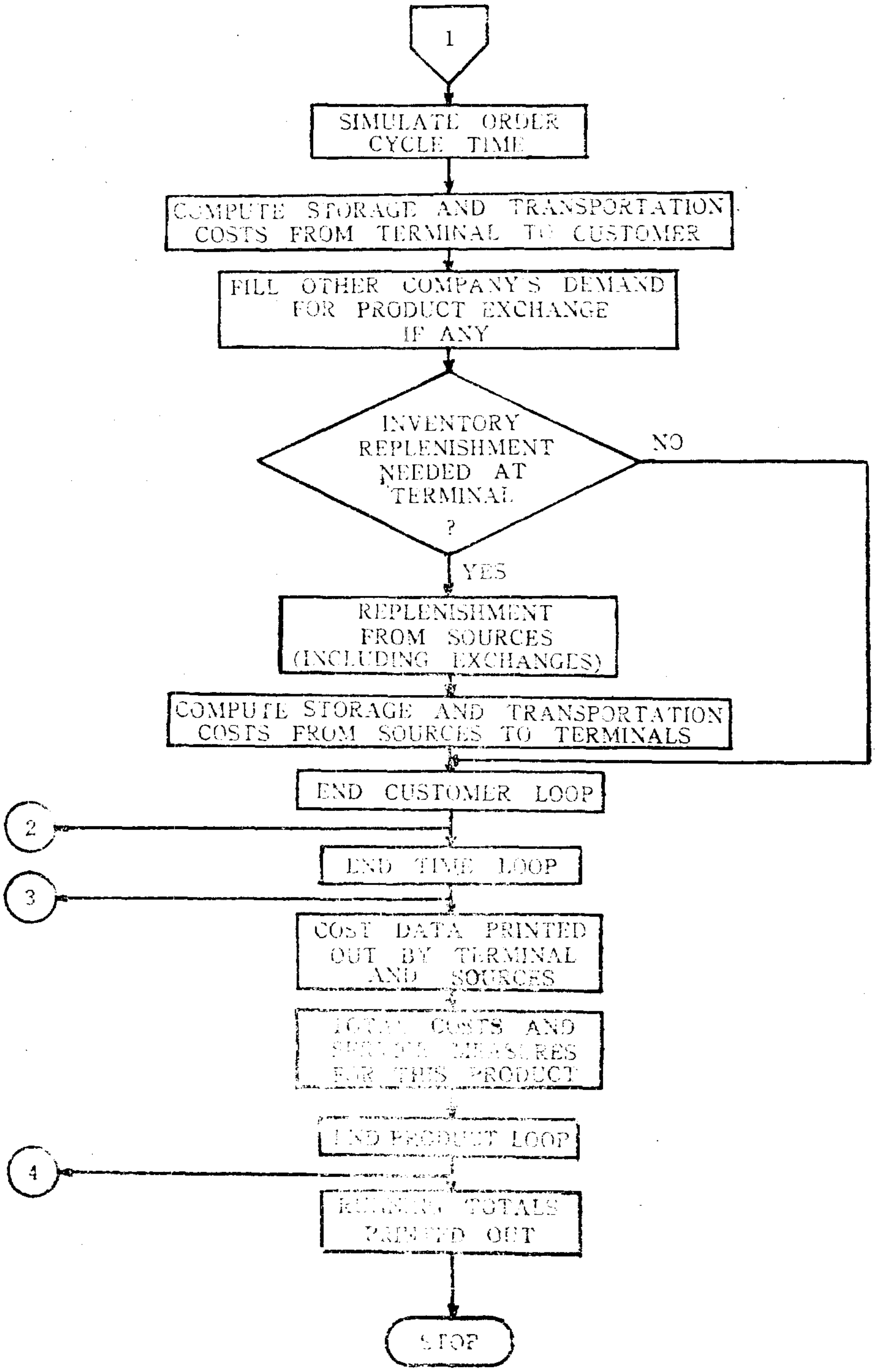
The reorder replenishment cycles are triggered for the terminal concerned by comparing MAX with the inventory on hand, orders due-in and backorders outstanding. The transportation cost for the shipment of product from the refinery to the terminal and the variable refinery storage cost is computed when a refinery shipment takes place.

After collecting all variable costs for all the customers for a certain day the program adjusts inventory level and product exchange balance. The grand variable costs and total fixed costs are collected after all time periods have been processed.

Finally, the program prints out the cost data, service performance information and other performance data by terminal, and for the total system.

Figure 3. A Brief Flow Diagram of the Simulation Model Operations




1
SIMULATE ORDER CYCLE TIME
COMPUTE STORAGE AND TRANSPORTATION COSTS FROM TERMINAL TO CUSTOMER
FILL OTHER COMPANY'S DEMAND FOR PRODUCT EXCHANGE IF ANY
INVENTORY REPLENISHMENT NEEDED AT TERMINAL ?
NO
YES
REPLENISHMENT FROM SOURCES (INCLUDING EXCHANGES)
COMPUTE STORAGE AND TRANSPORTATION COSTS FROM SOURCES TO TERMINALS
END CUSTOMER LOOP
2
END TIME LOOP
3
COST DATA PRINTED OUT BY TERMINAL AND SOURCES
TOTAL COSTS AND SERVICE MEASURES FOR THIS PRODUCT
END PRODUCT LOOP
4
RUNNING TOTALS PRINTED OUT
STOP

AN EMPIRICAL IMPLEMENTATION OF THE MODEL

The Objective of the Study

The primary objective of the study described here was to improve the design of the production-distribution system of the Korea Oil Corporation, capable of providing speedy customer service at the lowest distribution cost, based on a total multi-product, multi-echelon system approach. Specifically, the study was to determine (1) the optimum locations, number, and size of distribution facilities for long-run system planning purposes, (2) an appropriate inventory control system, (3) the value of extending the present arrangements for making product exchanges with KOCO's competitors' facilities, (4) the best mix of transportation modes required by product shipments for short-run planning purposes and (5) the necessary parameters for the system to support likely activities five years in the future, based upon a forecast of demand at that time. The general motivation for this study was to discover improvements over the present system. The hypothetical modifications developed and compared with the existing system include:

1. Distribution systems with both fewer and more terminals, optimizing, each time the number in the set was changed, the location of terminals with respect to distance from demand areas served and the demand density in those areas. It was hypothesized that the cost proximity of transportation is still relevant to the spatial proximity in a total system approach.

2. A total system approach to inventory control, based upon the multi-echelon production-distribution system that exists. It was hypothesized that such an inventory control system would result in lower total terminaling costs and higher (i.e., better) customer service levels than the present single stage oriented inventory system, which neglects interdependent cost effects on the other inventory stages in KOCO's multi-echeloned distribution system.

3. A system that provides more possibilities for utilizing product exchanges with other sources owned by KOCO's competitors. It was hypothesized that liberalizing exchanges at the refinery level and extending them to include four terminals owned by competitors, would lower distribution costs.

4. Making available improved transportation facilities, by: (1)substituting tank lorries (10 kiloliters or less capacity), (2) selectively extending the present pipeline system both (a) to serve the northeastern part of the nation, and (b) to ship the Seoul area's fuel oil requirements from the port of Inchon, and (3) providing an unlimited supply of all (feasible) transportation modes to the entire system. It was hypothesized that these improvements would result in lower total distribution costs and better service.

5. Forecasting the future market situation five years or so from now and analyzing the impact of changes upon the distribution system design. It was hypothesized that the capacity of the simulation model to predict the state of the system at some specific future time such as five years hence would provide a better basis for planning changes in the distribution system than the present method of reacting after market changes have taken place.

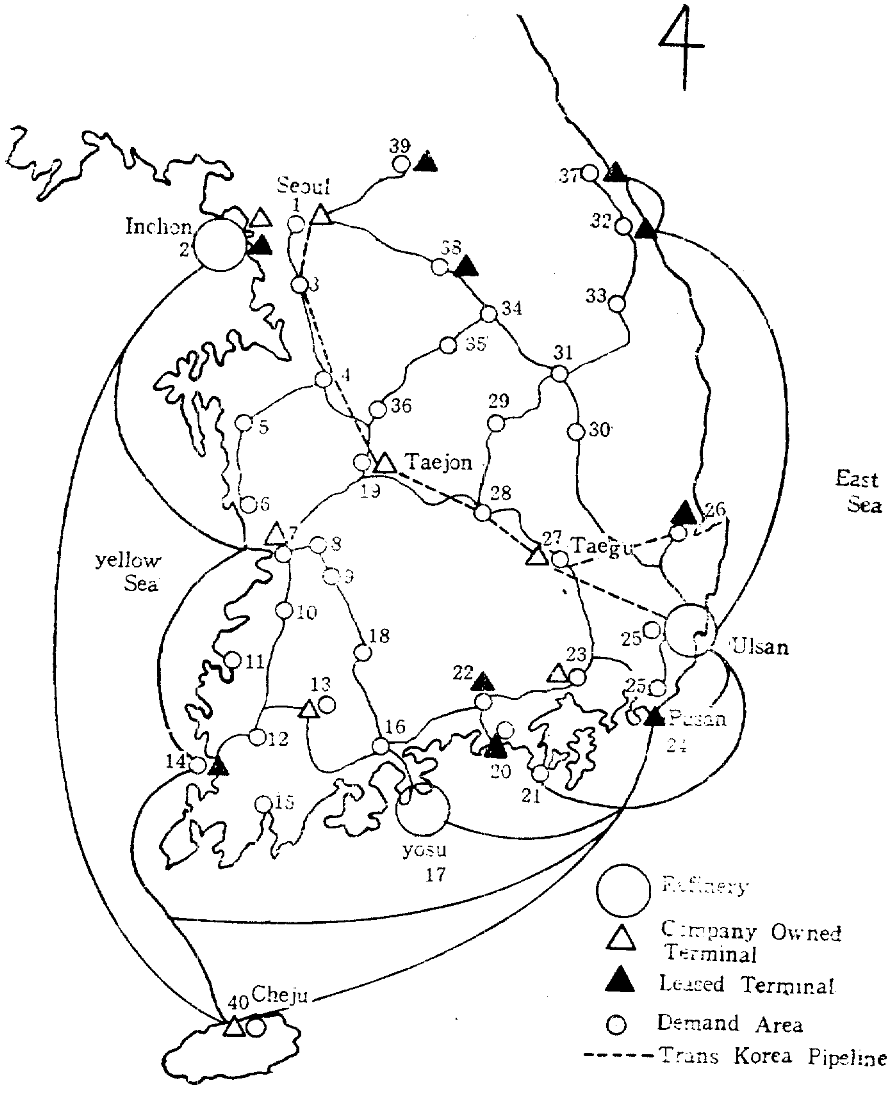
he Background of the Company Operation

The production-distribution system of the KOCO is comprised of 8 company owned and 20 major leased terminals, totaling 11 million barrel storage capacities. Producing and suppling 29 different refined petroleum products at the rate of 175,000 barrels per day for 250 major inductrial customers and over 700 gas stations, and thousands of households through 38 agent wholesalers and 2000 subdealers. It owns a few small coastal tank ships, nearly 700 rail tank cars, 175 tank trucks and a 260 mile pipeline system. The company controls about 65% of the national refined product market, the rest of the market is shared by its two main competitors, Honam Oil Co. and Kyung-In Energy Co. The geographical arrangement of these facilities is shown in Figure 4. KOCO refinery is located in Ulsan, Honam's in Yosu, and Kyung-In's in Inchon.

Input Data: Collections and Analyses

The Simulation runs in the experimental study were conducted for a period of 52 working days, representing two summer months. Demand for each of 6 major products in each customer area, other cost data and system control parameters such as beginning inventory of refinery and terminals, order cycle time, production capacity, product exchange quantity, are

Figure 4. Geographical Distribution of The 40 Demand Analysis Areas, Refineries and Terminals



collected from the company's actual operation for 1973.

There were 40 customer areas designated as pseudo-customers in this study: each of the 40 areas was also a possible terminal location.

For the studies relating to long-run system design, two different demand levels were used: one was the 1973 actual demand level; the other, a 1978 forecast of demand level. Using both the 1973 and the 1978 data sets, experiments were performed under two conditions with respect to possible product exchanges with KOCO's competitors: (1) exchanges limited to refinery level only, and (2) exchanges expanded to include terminals in addition to the refineries. For the short-run system design experiments, only 1973 data set was used to test selected hypothetical changes proposed in the distribution system.

Derivation of Demand Functions for the Customer Areas

The distribution functions of order size for the customer areas were identified by conducting a series of goodness of fit tests with a number of common probability distribution functions, including poisson, exponential, normal and uniform distributions. The goodness of fit between the actual distribution of order size with these functions was evaluated on the basis of several different test statististics obtained by using the Kolmogorov-Smirnov Test, the Cramer-Von Mises Test, the Moment Test, and Chi-Square test. The tests were conducted at the significance level of $\alpha=.05$ to identify for each customer area a theoretical order distribution function for orders that could be considered statistically equivalent to the actual distribution. Based on these distribution functions, the simulation model generates the individual order by the customers, using the pertinent parameters and functions that were generated by the test processes.

The first segment of the simulation model generates orders for a customer area until the sum of the generates orders becomes equal to the demand requirement of the area for the simulation run period, say 52 working days (representative of two months). The daily demands for each area were obtained by accumulating the generated individual orders for a given date. The dates in turn are generated by an order interval simulator inside the demand file of the program.

COST FUNCTIONS

Transportation cost Functions by Mode

Four alternative transportation methods are avilable for shipping products from the refinery through terminals to customers. Thery are tank trurck, coastal ship, pipeline, and rail tank car.

The freight rate schedules of unit cost-per-load-mile for rail tank car and coastal marine tanker are posted by the Ministry of Transportation. Shipping costs by pipeline are calculated based on the tariff charge per/ load as contracted between KOCO and the US military and actual pipeline operating cost for the company owned part of the system. Factors that affect transportation costs are:

1. The size of shipment
2. The distances between origins and destinations
3. The commodity classification of the product being moved, and
4. The avilability and capacity of transportation facility by modes.

The product shipments by tank truck are mostly common for the terminal-customer deliveries and short distance shipments for the refinery-terminal links. A transportation cost by tank truck can be approximated by a linear function developed in this study.

Based upon the actual historical tank lorry operating cost data and actual distances between the origins and destinations involved in the shipment, cost-per-barrel by size of truck was computed using the cost functions developed as below:

$$TC=F\left(\frac{2M}{S}+L\right)+V(2M) \tag{21}$$

where

TC= total unit transportation cost for shipping one barrel of product,

F= fixed truck and labor cost per barrel per hour,

M= distance in miles between origin and des tination(2 stands for round trip),

L= average loading—unloading time,

S=average speed of the truck per an hour,
V=truck variable costs per barrel mile

Terminal Operating Cost Functions

Terminaling costs includes two major components: Storage and handling cost and Inventory holding cost.

Storage and Handling Costs

These costs are broken down into fixed costs and variable costs. The most important items of fixed costs are depreciation and such organizational costs as labor and administration costs. Cost items such as container handling, receiving and loading, power, communication, and insurance are classified as variable cost.

Since the company both operates its own terminals and also employs leased terminals, two sets of terminaling costs are taken into consideration. As for the leased terminals the terminaling costs are directly proportional to the volume put through the terminal. The contracted rental charges per barrel are applied to calculate the terminaling costs for the leased terminals.

Based upon the company's actual cost data the fixed cost function was obtained by regression analysis of the actual monthly fixed costs of terminals according to the size of the company's existing terminals. The function was defined as follows:

$$F_J = .113S_J + 7115.36 \qquad (22)$$

where F_J stands for monthly fixed terminaling cost of terminal through put barrel according to the company's 1973 terminal operating cost and throughput data.

Inventory Holding Cost

Another major component of terminaling cost-the inventory holding cost or inventory carrying cost-is characterized by its linearity. More precisely speaking, it is a function of average inventory on hand, in transit and the duration of time for which inventory items are held, the amount of capital tied up by the inventory on hand, the cost of furnishing that capital insurance and storage losses. From a practical point of view the insurance and storage losses were dealt with seperately as the variable storage and handling costs in the study.

The total monthly inventory carrying cost may consist of carrying costs for two main components: (1) stock at terminals, (2) in-transit stocks both for the refinery-terminal and terminal-customer shipments. A function can be defined as:

$$TIC=(Q_p/2)IC_p+(X_pD_x)IC_p+(Y_pD_y)IC_p$$

$$\text{or } TIC=IC_p[(Q_p/2)+(X_pD_x)+(Y_pD_y)] \qquad (23)$$

where

TIC=total system inventory holding cost per month (or year),
I=interest rate or capital cost rate to apply to the capital invested in inventory,
C_p=unit cost of product p in stock,
Q_p=average order quantity of product p at terminals,
X_p=shipments of product p from refinery and other sources to customers,
D_x=transportation delay time for X_p,
D_y=transportation delay time for Y_p,

Depletion Cost Functions

Two kinds of costs may be incurred when the system is out of stock: backordering costs and lost sales costs (Hadley and Whitin, 1963).

In the case of backordering, backorder costs may be considered a function of the number of units which are lacking to fulfill an order, and the duration of time, t, for which the backorder cost for a period of time, t, $B(t)$ was computed in the form as follows:

$$B(t)=b+Irt \qquad (24)$$

where

I=daily interest rate,
r=unit gross profit margin per barrel,
b=fixed portion of backorder cost which stands for intangible costs, such as loss of customer's goodwill and some tangible administration cost involved in handling backorders.

The penalty cost, or the cost of a lost sale, on the other hand, involves not only a loss of gross margin but also extensions of the elements included in backordering cost intangible goodwill loss, and the other administrative expenses relevant to the backordering. At some point in time, a backorder results in lost sales for both the customer and the company. It was decided to classify as lost sales those backoders that remain unfilled after the customer's estimated stock of the item has been exhausted (or, a time equal to his replenishment lead time plus order precessing time). The penalty cost per barrel during time t can be determined in the form,

$$
\begin{aligned}
L(t) &= (r+\alpha r)t \\
&= (1+\alpha)rt \qquad (25)
\end{aligned}
$$

r and t are the same as denoted for backordering cost and α stands for the penalty coefficient applied to r representing the lost sale cost besides the lost margin, r per barrel.

In the case where an order first became a backorder, and then was not filled before the KOCO customer's stocks of a product were exhausted, the depletion cost was the sum of two costs: a backordering cost daily until the customer reached the point of being out of stock, and a lost sales charge from that time until the shipment was ultimately received by KOCO's customer. In this case the depletion cost function will be expressed, combining the Equations (24) and (25), as below

$$D = B(t_1) + L(t_2)$$

or $$D = b + [It_1 + (1+\alpha)t_2]r \qquad (26)$$

where D stands for total depletion cost over the time period (t_1+t_2) : t_1 is the duration from the time a backer is posted when stockout occurs until delivery is received.

VALIDATION OF THE MODEL

The multi-stage validation approach (T. Naylor and J. Finger, 1967) was employed for validating the simulation model as a whole and the input data generated for the simulation precesses. The first procedure, which requires a measure of the extent to which the model as a whole is an accurate representation of the real system, was done by comparing the total outcome predicted by the model with the actual historical outcome in terms of major factors such as total shipments, fixed and variable terminating and shipping costs and so forth. The comparison rate between the predicted outcomes and actual outcomes was.984

The second procedure for the validation was to determine of the model-generated data, based on the endogenous variables are used, are identical with the actual data, whether they are statistically under control.

The results are appraised by using either statistical or nonparametrical techniques, depending on the characteristics of data to be checked; in most cases at a 5 percent confidence level, $\alpha=.05$, is used.

Figure 5 shows one of the validation results for simulated order size.

The actual distributions for the size of order for gasoline in Seoul very closely agrees with the negative exponential distribution generated by the model. The Kolomogorov-Smirnov test statistics for a goodness of fit test was 06214, p—value〉. 20 at the .05 significance level.

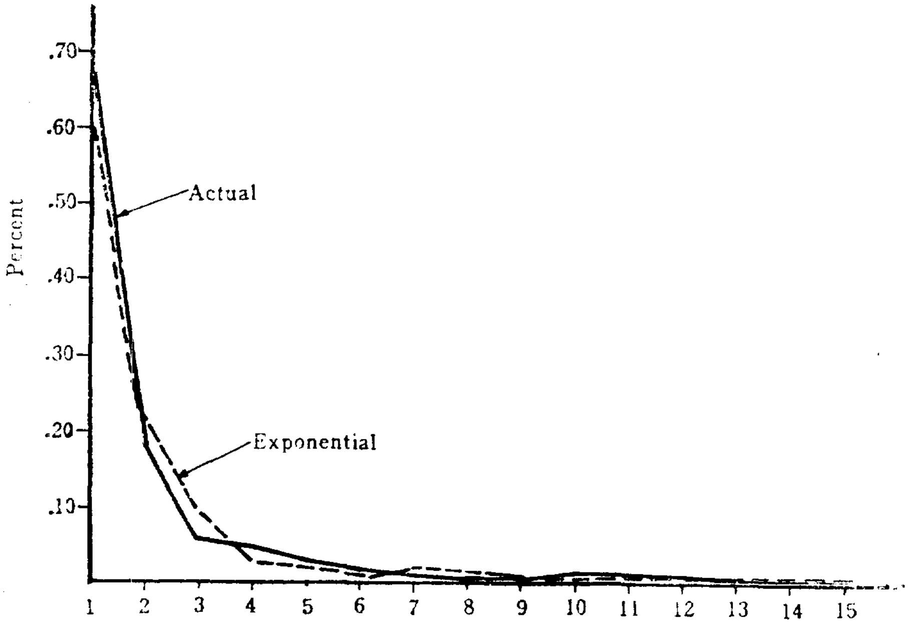
RESULTS AND IMPLICATIONS

For the long-run system design, the simulation experiments identified the optimum terminal system as having 8 terminals for 1973 demand level and one having 10 terminals for 1978 foercast demand data. Figure 6 shows the least cost terminal system in terms of total distribution costs and the terminal locations and customer assignment for both opitmum systems with the one for the existing system are seen in Figure 7. In both of these optimum systems the terminals were smaller than the existing ones, and consist only of company owned terminals instead of leased terminals, both changes resulting in reduction of the system's total costs and raising the level of customer service. The result imply that total capacity requirements for terminals can be reduced by one third of the existing terminals requirements by utilizing unlimited product exchange with the other companies' terminals and refineries based upon forecast of customer demand by market area and conform to the requirements to the total system as a whole, and better inventory control system.

With respect to short-run system design changes, an inventory control system that includes a secondary and tertiary search for supplies to meet a customer's order than did the policy of restricting customers to their primary assigned terminal.

This finding implies that basing shipments solely on the nearest terminal to the market area does not necessarily result in the lowest distribution cost or the best customer service level in a multi-staged total system like this one. There is no correlation of cost proximity and spatial proximity in total approach, in which interdependent cost effect on inventory system is considered.

Figure 5. Distribution of Order Size for Gasoline Demand in Seoul, 1973



Size of order^a

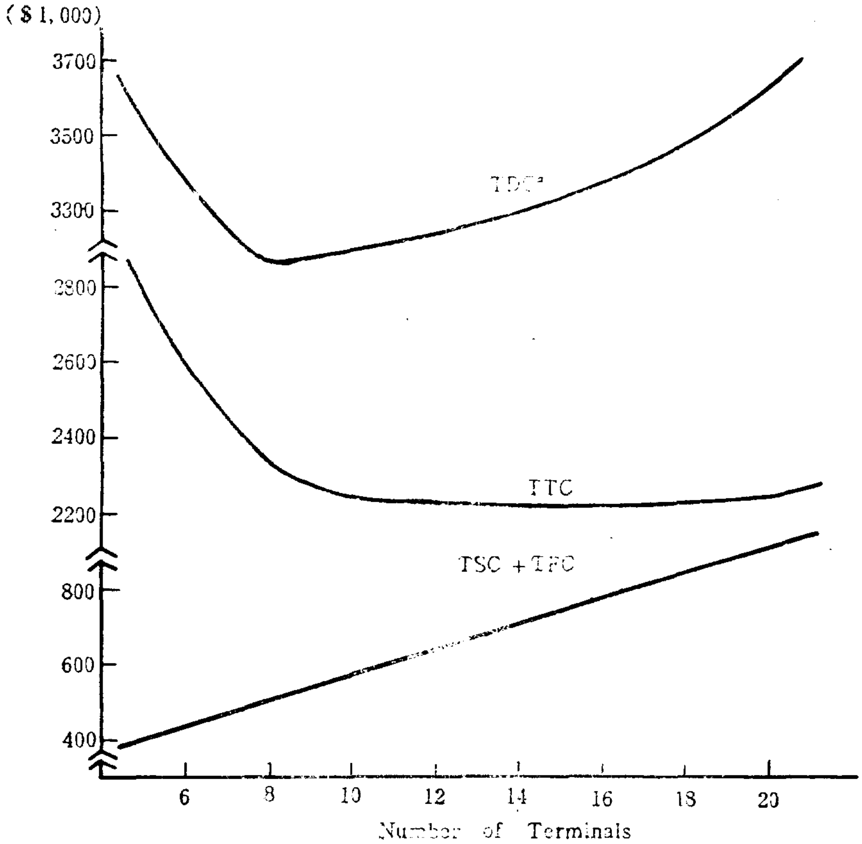
^{a} Class range of each class is 72 barrels.

The theoretically determined value for the inventory control system parameter, MAX, was found to perform much better than the presently used "Desired Inventory Level" by the company in terms of cost and service performance.

This implies that inventory control should be based on an adequate control pararmeters, which are closely relevant to the customer-terminal relationship from the total system approach point of view, so that the interdependent cost effects on the other inventory stage in multi-echelonic distribution system are taken into consideration.

A liberalization of product exchange practices based on total company requirements is recommended. However, the recommendation would apply only when it could be incorporated into the optimum terminal system(s) rather than the present 19-terminal system.

Figure 6. Total Distribution Costs (TDC) and Their Major Components for Different Number of Terminals As Determined by the Simulation Model with the 1973 Demand Data.



Total Backordering Cost (TBC) and Total Net Location Differential Costs (TLC) are included in TDC.

Figure 7. Terminal Locations for the Existing System and the Least Cost Systems for 1973 and 1978 Data Sets[a]

Terminal I.D. No.	KOCO'S 1973 Existing System	Optimum 1973 8-Terminal System	Optimum 1978 10-Terminal System
1	X	X	X
2	X	X	X
3			
4			
5			
6			
7	X	X	X
8			
9			
10			
11			
12			
13	X		
14	X(L)		
15			
16			
17	X(R)	X(R)	X(R)
18			
19	X	X	X
20	X(L)		X
21			X
22	X		
23	X		
24	X		
25	X	X	X
26	X(L)		
27	X	X	X
28			
29			
30			
31			
32	X(L)	X	X
33			
34			
35			
36			
37	X(L)		
38	X(L)		
39	X(L)		
40	X(L)		

[a] (L) stands for leased terminal, and (R), other company's refinery

Extension of the pipeline to remote northeastern areas was unprofitable, but extending the pipeline from Inchon to Seoul for fuel oil only proved superior to making shipments by large, efficient trucks. In other areas, however, using larger trucks to replace existing smaller trucks and rail shipments promises large savings.

Pipeline as the cheapest mode, however, can not necessarily be efficient if there is limitation on product exchanges.

In general, the transportation system is suggested to be revised first by using larger trucks to replace the smaller and uneconomical ones, and second by expanding the use of the cheaper modes such as truck and pipeline to replace the more expensive and less flexible ones in as many customer areas as possible.

CONCLUSION

For the company concerned, a principal contribution of the study is to provide a better planning tool for its long-and short-range system design. Specifically the study shows value of a better information system and more useful managerial data such as transportation cost, demand forecast by market area, inventory carrying cost, depletion cost and so forth, which are not properly utilized in the existing system. A centralized inventory control of terminal stocks was implicated to be recommendable.

For production-distribution system design theory, generally, the most significant feature of the study is the three model approach, which combines two analytical and one simulation model as a methodology for improving the optimality of a solution for the problem of determining the location and number of terminals (warehouse).

A total system approach to inventory control, merging spatial and temporal factors for multi-level,-product, -location system is proposed.

The study provides the management in the petroleum and other similar industry with a capability for low-cost modeling of such a complex system. An improved mothod is also advanced for more accurately estimating the size of storage facilities needed through two-step procedure together with determining the number and location of facilities. The model also provides better way to utilize storage and transportation facilities for the industry as a whole on a nationwide bases.

On the other hand, as with/all mathematical models, the simulation model and its related preliminary models developed in this study suffer from the inherent difficulties of trying to capture the essentials of a complex real-life system. Some limitation can be considered for the study. Through the simulation experiments, individual shipments of products are implicitly assumed to be made with only one product loaded on the delivery vehicle. Such a procedure would be uneconomical. In practice, a terminal often receives a delivery of not one but different products from the same ship, rail tank car, or truck which has been loaded at a simple source. However since the model used the average unit cost for each transportation mode, by individual shipment the effects of this implicit assumption on total costs probably are not significant.

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