THE DESIGN OF A REFINED PRODUCTS DISTRIBUTION SYSTEM

by

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B. S., Clemson University, 1968

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

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1971

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

The author would like to express his appreciation of the guidance provided by Dr. L. E. Grosh in this research effort. Thanks go to Dr. Said Ashour for suggesting the area of investigation.

CHAPTER I

INTRODUCTION

There are very few manufacturing concerns which enjoy the position of having customers come to their factories to purchase products. Some type of distribution system must exist in order to get the products into the hands of the customers, through final sales outlets. In highly competitive product areas these distribution systems are of greater importance, as the customer looks not only for a quality product, but also for service and convenience in purchasing. Even a company enjoying a monopolistic position would require some means of distributing its products if its marketing area was of any considerable size. Distribution systems exist in varying degrees of complication and sophistication, depending on the industry, the company, and the particular product. The numerous storage, handling, and transportation operations taking place between factories and final sales outlets may contribute greatly to the cost of a product. Planning and coordination of these activities for efficient operation requires the solution of production scheduling and inventory control problems, choices of alternative equipment, selection of plant and warehouse locations, and numerous other applications of the methods of management science.

Problems encountered in petroleum operations are somewhat unique due to the fluid property of the raw materials and most finished products. Crude oil stocks and finished products are often easier to transport, and can be handled by relatively continuous processes which introduce certain economies in transportation yet create special problems in production scheduling and inventory control. Greater interrelationships exist between the various functions of exploration and production, refining, and marketing than are found in most other manufacturing operations, as will be seen in the following brief discussion of petroleum operations. Because of these interrelationships, the effects of changes in any company function are more evident throughout the rest of the operations than with industries whose various activities are more discretely separated.

Most crude oil stocks are produced in areas remote from the major demand. The production of crude can be scheduled by linear programming techniques so as to minimize the cost of meeting the requirements of the refineries for quantities of specific types of crude within restrictions imposed by equipment capacities and the production rates allowable by government regulation and physical pumping phenomena. The crude oil removed from the earth is collected in gathering systems from the individual wells and transported to the refineries through extensive, specialized facilities: pipelines, tank trucks, railcars, tankers, and barges. For a required slate of finished products, some crude types are more desirable or profitable to refine than others. It is common for an oil company to exchange crude oil at a given location for the crude of another company, either because of economics of transportation or more desirable properties of the other crude. The evaluation of the profitability of the exchange of a proprietary crude for another company's crude, given the configuration of refineries and associated economics of transporting and processing one crude rather than another can be carried out through the use of linear programming (Wagner 11, 59).

Some refineries run the same feed stock blends continuously, creating the same products all the time. Others vary the feeds to get different product mixes, as changes in demand require adjustments in operations. For example, a greater demand exists for fuel oils in winter, while gasoline demand peaks in summer. As flows of crude oil and refined products cannot be exactly syncronized with market demands, problems of inventory control of feed stocks and finished products arise as well as production scheduling problems. These problems are further complicated by limitations on the maximum and minimum amounts of each product obtainable from the available crude, i.e., there is a maximum amount of gasoline which may be refined from a barrel of crude oil, and in refining this gasoline there is a minimum amount of fuel oil which will result due to the composition of the crude and the limitations of refining process technology.

These problems have yielded to various techniques of mathematical programming. Linear programming formulations are widely utilized in the selection and blending of crude stocks to be refined to meet product demands within crude availability and equipment throughput restrictions. This planning of weekly or monthly minimum cost production schedules for refinery unit operations must also consider the range of performance characteristics of the resulting products. Many refined products may be blended from basic stocks to obtain required quality characteristics such as vapor pressures and octane ratings. In the case of octane ratings, the quality varies nonlinearly with the amount of tetraethyl lead added to the mix, a smaller octane rating increase resulting from additional increments of "lead" added. Blending the basic stocks to obtain a desired slate of final products is thus a nonlinear programming application, which has been solved using linear approximations and an iterative linear programming technique known in the industry as "recosting." Not only have some companies combined the two previous mathematical programming problems into one model, there have been attempts to "optimize" the scheduling of all of a company's refineries simultaneously, given certain marketing goals. A more generally used analysis also involving mathematical programming is the evaluation of exchange agreements with other companies for final products, analyzed in similar manner to the exchange of crude stocks previously discussed.

While products such as greases, lubricating oils, and special chemicals are packaged in discrete quantities for storage and shipment, the motor fuels, distillates, and petroleum gases may be held in large tanks for future demand and eventual shipment, or transferred directly to the final sales outlet. There are several alternative modes of transportation for refined products which presents another problem. Products must be routed from various refineries to a number of marketing areas using the least cost mode of transportation recognizing factors of differentials in costs of manufacturing products at these various refineries, shipping costs, and the seasonal variations in consumer demand for the refined products.

Pipelines are generally the cheapest transportation method for high volume shipment of products. The pipelines also require a higher initial cost to build, thus a number of companies often share a pipeline, each having refineries on the line. Several products may be shipped through a given pipeline thus creating problems in pipeline scheduling. Various considerations of pipeline scheduling include determination of optimal storage tank sizes and optimal shipment quantities, as well as the timing of the shipments. Usually there are several bulk stations along a given pipeline where the products are removed and stored in anticipation of future demand. At these points, products may be transported to final sales outlets or shipped to other intermediate storage facilities.

The use of barges and tankers to ship refined products is common to refineries located on waterways. Many oil companies own fleets of tankers and barges rather than hire common carriers. Tanker and barge scheduling problems are as difficult as pipeline scheduling. Given a fleet of vessels, a company has to set a timetable for each vessel in order to meet all the demands for products. Considerations must be given to storage facilities at the source and destination as well as to the maximum utilization of the vessels.

A fully integrated oil company produces a wide range of products: natural gas, gasolines, kerosene, fuel oils, chemicals, lubricating oils, greases, waxes, asphalt, fertilizer, synthetic rubber, plastic resins, and even synthetic fibers. The most familiar products include the distillates and motor fuels, however. It is the specific area of motor fuel distribution that will be researched herein, and the discussion will continue in this context, although most comments may be extended to other products. Highly competitive conditions usually exist in gasoline marketing; there are a lot of promotional efforts, advertising, and price wars. Further, the industry is faced with rising labor costs, higher crude prices, and more recently, increased manufacturing costs for low lead and lead free motor fuels. All of these factors call for improved operational efficiency.

Distribution systems for motor fuels exist in varying degrees of complexity from one company to another, complicated by the fact that most oil company final sales are handled through jobbers as well as company owned stations. At a given terminal, a company usually has its own fleet of vehicles, which delivers the motor fuels to the service stations of jobbers and company owned stations. In many instances, however, jobbers own trucks and receive their stocks of motor fuels at the bulk terminals. The company may also serve independent distributors from a terminal, as well as other major oil companies by exchange agreement.

The operational policies of most companies have developed over the years largely from the experiences of the people most directly involved in the day to day operations. Thus a wide range of variation is found in the operating procedures of different bulk terminals. A given set of procedures may vary within the industry, within a company, and even within a sales district.

The method of payment for a shipment of products may be on consignment, cash on delivery, 90-day credit, or a number of other policies. For a company selling to dealers on a consignment basis, a typical situation involves the periodic reading of pump meters by a company representative who reports his readings to a sales office. The required amount of product to be delivered is then calculated and the billing and ordering processes are carried out, the station being billed for the previous volume sold. The terminal dispatcher is given a manifest each day of the required deliveries, and he assigns vehicles to make the drops. This scheduling and routing of deliveries is normally based on the experience of the dispatcher.

Of course there is a lead time involved in the ordering process between the reading of the pumps and the actual delivery. During this time stockouts may occur, as most often there is little consideration given to setting safety stock levels. The company representatives merely make their visits at specified intervals, taking orders for the various products, and in some cases auditing the station. The resulting order sizes may vary greatly, no optimal order size having been set.

Another widely used procedure is that in which each station manager orders a new supply directly from the terminal. He may or may not have been told when to reorder, in terms of a reorder point. This policy often is associated with cash on delivery sales. Of course, the station managers will then order only when they feel they can pay, or may tend to order smaller quantities so they do not have to release large amounts of their cash. This policy creates an excess of emergency situations, when station managers wait until the latest possible minute to order, and then need to be supplied right away to avoid runout. Generally the deliveries for a particular day are not known well enough in advance to efficiently plan the routes of the delivery vehicles.

With the availability of various analytical techniques, it is now possible for an oil company to examine the procedures for operating a distribution system and improve the operations. Within the distribution system composed of a bulk terminal and all service stations served by company owned vehicles from that bulk terminal, there are several areas in which research may yield improvement in operations. The stimulus that sets this distribution system into action is consumer demand, a variable beyond control to a large degree except through promotional efforts. Thus, it is highly desirable to develop information about demand patterns, with regard to average demand rate, growth trends, seasonal effects, and random day to day fluctuations, as these factors directly affect the safety stock levels and economic order quantities, thus affecting order frequencies. The logical starting point for any system improvement would then be to examine and analyze past data to determine the factors affecting the pattern of demand. If the components of the demand patterns can be identified and quantified, the proper forecasting model can be developed. This leads the way to inventory control studies, a logical objective of which is to set safety stock levels and reorder points at each station. An inventory control study would also result in determination of economic order quantities and order frequencies. In consideration of the pertinent costs in the inventory study, stock out costs (opportunity costs), ordering costs, and inventory carrying costs would be straight forward. Transportation costs, however, would be difficult to consider as the efficiency of dispatching vehicles depends not only on the routing schemes but on the size of orders (full loads or fractions). Although much research has been done on developing vehicle routing algorithms, most of them are difficult to apply to dynamic and/or probabilistic situations. The more practical routing algorithms developed to date are based on heuristic methods, and do not guarantee an optimal solution to a given problem (Cochran 3; Tillman 10). In determining a routing scheme with these proposed techniques, the description of the fleet of vehicles available at the terminal is required as a restriction in the development of routes. Information on the number of vehicles, size of each, and size of compartments is required. These programs could easily be run with varying fleet descriptions to simulate alternative equipment specifications in an effort to find the best combination and number of vehicles.

Evaluation of bulk terminal loading equipment and procedures is another area for improvement. With the demands on a terminal given, design of loading facilities to serve this demand can be analyzed through simulation (Collins 4). This type of study generally includes the examination of alternative arrangements of assigning products to loading racks, number of racks required, as well as the number of spouts on each rack. The normal considerations of equipment specifications, pump sizes and storage tank sizes are evaluated concurrently. These alternatives are aimed at changing the service time distribution. A less obvious, nonetheless important consideration is the possibility of altering the customer interarrival time distribution. This would be more feasible and more effective in situations where a larger per cent of a terminal's volume is delivered by company owned vehicles. The servicing of demands with these vehicles could very well be shifted to night or periods when the terminal is not overloaded.

1.1 Problem Definition

Within the time restriction, the scope of this thesis cannot embrace all of the above enumerated problems. Therefore attention is focused on the smaller segment of the distribution system consisting of a bulk terminal and all of its facilities, including the fleet of vehicles at that terminal, and the company owned service stations served from the bulk terminal. Each service station is assumed to sell only two products, regular and premium gasolines. Although other products such as diesel fuels and non-leaded gasolines may be sold at a station, these products are not considered directly. The proposed analysis for the two motor fuels can be extended to include other products, however.

The data provided for this thesis includes actual daily gasoline sales volumes for regular and premium sales from a major petroleum company, for two consecutive years, beginning on December 26, 1966 and extending to December 29, 1968. All of the stations operate seven days a week. The figures are taken from detailed audit computer listings as provided by the company's controllers department. A sample of twenty-five company owned stations located in the same marketing area, all served by the same bulk terminal is used. The sample excludes the jobber owned stations. An area where good district sales management had been practiced was selected by a company sales department technical analyst. Areas where abnormal competitive conditions had existed were avoided. In addition the area was selected because it gave a good cross section of the various site types: residential, shopping center, interstate, and business district. The area itself was not revealed, as this information would expose the company's competitive position in that area. The Tulsa area has been assumed by the author, and station locations are placed on the Tulsa map in accordance to actual station locations where possible. The bulk terminal is assumed to be located at an actual refinery location in Tulsa (not belonging to the company supplying the data). From this hypothetical station distribution, the interstation distances and travel rates are estimated using the most reasonable routes between the points. The travel times are then calculated from this information. The rates, thus the times, are assumed to be constant with regard to time of day. Table 1.1 displays the rates, distances and times. Each station is identified by site type, and the storage tank capacities for each product are given. This data is presented in Table 1.2.

Uniform operating hours for all stations are assumed, with no preferential delivery times. A consignment sales policy is assumed, as this is the only policy which allows the company to deliver at its own convenience. Under this policy the company bears the costs of carrying inventory, including leakage, evaporation, and theft from the tanks. The costs of the products at the terminal are given, and are assumed to be constant with respect to time and order quantity. Estimated inventory carrying cost is also given. Stock out costs are not available.

The bulk terminal is assumed to have a sufficient supply of product to meet all demand. The cost of operating 8000 gallon tank trucks is given in terms of drivers' hourly wages, yearly costs of taxes and licensing, and the operational and maintainance costs per mile driven. The total daily availability of the vehicles, shift lengths, number of shifts per day, and total allowable overtime are investigated. The vehicles are assumed to have two compartments for one case, the industry range being from 2 to 6 compartments per vehicle. The sizes of the two compartments are variables to be investigated in the study. As another alternative in the simulation, separate delivery of each product is also to be investigated (non-compartmentalized vehicles). The terminal is assumed to operate 6 days a week. In actual practice periods of terminal congestion may occur due to queueing at the loading facility. This would add an additional time variable, vehicle waiting time, which would be from some distribution dependent upon time of day. Since this information is not available, instant service is assumed, with a constant time assumed for each truck loading of 15 minutes, during which time the vehicle is positioned at the loading facility, set up for loading, and the delivery manifest prepared. A loading rate of 400 gallons per minute is given and used to determine a variable loading time dependent on the volume of product being loaded. Likewise for each delivery a constant time of 15 minutes is assumed, with a given unloading rate of 450 gallons per minute used to determine the variable unloading time.

In the case of the emergency order situation, the orders are assumed to be expedited. In the real situation, there is a chance of a stockout at a station placing an emergency order if a vehicle were not immediately available. As the demand distributions on smaller time scales are not known, it is not possible to express the probability of this stockout, nor the expected number of gallons of lost sales. The normal waiting time, however, is known to include waiting time for the availability of a vehicle plus loading time plus travel time. The company supplying the data reported a normal order lead time of 1 day for gasoline orders, with about 25% of the orders being placed on the day delivery was required.

All information assumed by the author had been discussed with a member of the operations research staff of the company to verify the reasonableness of the assumptions. The cost information and other given information is summarized in Table 1.3. The time series themselves are too lengthy to be presented.

1.2 Proposed Research

Within the distribution subsystem defined in the previous section, there are several possible areas for operations improvement. Decisions in this area are confined to shorter range problems for the most part, generally those dealing with delivery scheduling and inventory control. Some type of inventory control policy always exists for any system where stocks of products are needed to meet demands, by default if not established. In this case these policies are rough rules of thumb, a popular rule being to keep stock levels above 25% of tank capacity. This level is not arrived at strictly from inventory considerations, but because of water and dirt accumulation in the storage tanks. Mathematical derivation of an inventory model is not an objective of this research, as there is known to exist a complicated relationship between the delivery scheduling and inventory policy. In a mathematical inventory model, there should be a term reflecting the cost of delivery of various size orders, considering the probabilistic nature of the demand during delivery lead time, as well as the costs of transportation when deliveries to more than one location are made on a single route. This indicates the interaction among the station locations considered in overall distribution planning. In determining order sizes independently for each station, the optimal order size for a given location may be less than a full truck load, however there may not be enough remaining vehicle capacity to deliver the specified order quantity to another station. An optimal reorder policy would consider the overall effect of reducing one or both of the quantities to allow for better vehicle utilization, and then give an order size minimizing the total system operating cost. The effect of reducing the order size below that derived considering each station independently would be an increase in order frequency. Again, the model would be further complicated if the probabilistic nature of a station's actual requirement were considered. Thus it is evident that some coordinated ordering procedure among the stations is needed, which balances the costs of carrying inventory and order placement against the conflicting costs of vehicle utilization.

In addition, the problem of demand variability with a growth term and seasonal effects would prevent any simplifying assumption of constant demand, without badly distorting the results. Thus some other approach is desired. Simulation is felt to be the most practical approach. Reorder levels are to be assumed and, attention focused on the scheduling considerations, with effects on the inventory system examined. Factors for reduction of order sizes are to be examined, as well as vehicle compartment sizes simply by case study. The actual arrangement of stations on routes has already been researched, and several algorithms are available to facilitate the routing. A modified Clarke and Wright procedure (Cochran 3) is chosen to model the routing or dispatching process, extended to accept compartmentalized vehicles and consider order size reduction. This algorithm has proven to be reasonably fast computationally and gives good results.

In order to examine any of the alternatives to delivery planning and order actuation, it is first necessary to develop a demand modeling procedure to provide a simulated demand process to the inventory-delivery simulation. This comprises a significant portion of the research.

DISTANCE MATRIX

	T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	4.1																								
2	11.0	6.9																							
3	10.3	3.9	2.3																						
4	7.0	2.9	4.3	2.6																					
5	3.2	6.6	7.7	7.1	5.9																				
6	3.3	8.4	9.5	8.9	7.6	1.8																			
7	6.8	3.0	4.2	3.5	2.2	3.7	5.5																		
8	3.5	6.0	12.6	10.6	8.5	6.6	6.8	8.6																	
9	7.5	3.3	3.8	2.7	0.5	5.0	6.9	1.4	9.5																
10	2.0	6.0	10.3	9.7	8.4	2.6	1.4	6.3	5.3	7.6															
11	7.0	5.1	4.3	6.6	4.3	3.7	5.5	2.3	8.9	3.8	6.3														
12	6.0	7.5	15.0	12.5	10.3	9.0	9.4	10.9	2.4	11.0	7.8	10.8													
13	5.6	1.9	8.8	6.9	4.9	8.5	9.3	4.9	4.3	5.3	8.0	7.2	5.7												
14	7.7	4.0	9.0	6.9	4.9	10.6	11.1	7.2	4.9	5.5	10.0	9.2	5.7	2.1											
15	7.7	4.0	11.0	8.9	6.9	10.6	11.6	7.2	4.9	7.5	10.3	9.3	3.5	2.1	2.0										
16	9.2	5.1	4.0	1.9	3.9	8.0	11.6	6.0	10.9	4.4	10.9	8.3	12.9	7.0	7.3	9.1									
17	3.3	3.0	8.0	5.9	3.7	3.7	5.6	4.0	4.6	4.3	4.9	4.1	6.9	4.9	7.1	7.0	5.9								
18	2.7	1.5	8.3	6.5	4.3	5.3	7.2	4.5	4.3	5.0	4.7	4.6	6.1	3.3	5.5	5.5	6.6	1.6							
19	9.7	5.9	7.2	4.9	6.8	11.4	13.2	9.2	7.0	7.6	12.2	11.4	7.5	4.3	2.0	4.1	5.1	9.1	7.6						
20	9.3	5.5	8.7	6.5	6.4	12.2	13.5	8.6	6.6	7.2	11.7	11.0	6.0	3.7	1.6	2.6	6.7	8.6	7.4	1.6					
21	9.1	4.9	6.0	3.0	5.8	9.4	11.3	8.0	10.1	6.3	11.1	10.3	11.7	5.8	6.0	8.2	3.1	8.0	6.4	4.1	5.6				
22	3.3	4.0	10.9	5.1	7.1	6.6	8.6	7.0	1.7	7.6	5.2	7.2	4.1	2.3	4.3	4.3	8.9	2.9	2.6	6.4	5.9	7.8			
23	3.7	2.6	9.4	7.4	5.5	6.3	8.0	5.6	3.1	6.0	5.5	5.7	5.2	2.4	4.5	4.6	6.9	2.6	1.0	6.6	6.0	6.5	1.4		
24	7.2	3.1	6.2	4.0	3.9	9.7	10.7	6.0	6.3	4.5	9.2	8.3	8.7	2.9	3.0	5.0	4.2	6.1	4.5	3.1	2.6	3.0	4.9	3.6	
25	5.5	1.3	6.3	4.1	2.1	7.9	9.7	4.2	6.6	2.7	10.2	6.4	8.3	2.7	2.7	4.8	4.3	4.3	2.8	4.9	4.3	4.2	4.7	3.4	1.8

RATE MATRIX

	T	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	20.0																								
2	20.0	25.0																							
3	20.0	30.0	25.0																						
4	20.0	20.0	25.0	25.0																					
5	30.0	25.0	30.0	35.0	35.0																				
6	30.0	25.0	30.0	35.0	35.0	40.0																			
7	35.0	25.0	30.0	35.0	35.0	40.0	40.0																		
8	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0																	
9	20.0	20.0	25.0	25.0	20.0	40.0	40.0	40.0	20.0																
10	30.0	25.0	30.0	25.0	25.0	30.0	30.0	35.0	20.0	30.0															
11	30.0	20.0	30.0	25.0	25.0	30.0	35.0	35.0	20.0	30.0	30.0														
12	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0													
13	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0												
14	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0											
15	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	25.0										
16	20.0	20.0	25.0	25.0	20.0	30.0	35.0	35.0	20.0	25.0	20.0	30.0	20.0	20.0	20.0	20.0									
17	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0								
18	20.0	20.0	20.0	20.0	20.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0							
19	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	20.0						
20	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	20.0	25.0					
21	20.0	20.0	25.0	30.0	35.0	45.0	45.0	45.0	20.0	45.0	40.0	40.0	20.0	20.0	20.0	20.0	30.0	20.0	20.0	25.0	20.0				
22	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0			
23	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0		
24	20.0	20.0	20.0	20.0	20.0	25.0	25.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	25.0	20.0	20.0	
25	20.0	20.0	20.0	20.0	20.0	25.0	25.0	20.0	20.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0

TABLE 1.1