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Optimizing a Bulk Petroleum Logistics System

Abstract

This paper discusses the principal factors pertinent to optimizing a bulk petroleum product supply system. An illustrative situation is assumed using tanker delivery to four marine terminals. Transportation equipment, terminal facilities, and product inventories are the three major elements. Each is seen to be subject to a number of constraints affecting both selection and operation. Some limitations are individual and some are general. The effect of the constraints tend to be interacting in varying degrees. Attainment of the optimum in investment and expense requires a considered balancing and integration of transportation, terminals, and inventories. Further balancing is required in recognition of current needs and probable future developments.

OUTLINE

1. Introduction
2. Generalized Analysis
   Corporate goals, functional interrelations, transportation methods, economics
3. Ship constraints
   Size, speed, harbors, pumping rates, utilization, specialization
4. Inventory constraints
   Quality, size deliveries, frequency of deliveries, transit variations, type business, operating conditions.
5. Terminal constraints
   Peak inventories, flow rates, berthing facilities, quality, interchangeability, future development
6. Summary

1–INTRODUCTION

The planning and operation of an integrated petroleum company involves a full recognition of and application of the systems type of thinking. This broad viewing has extended typically from the well to the consumer. Probably this approach has been applied because of the substantial capital commitment decisions that had to be taken. Perhaps it would be more accurate to re-

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**Manager—Coordination and Supply Division Transportation Department, The Atlantic Refining Company* cognize that the range extends beyond the well because of the major expenditures of the acquisition of "hunting rights" to go look for oil with the hope that exploration will lead to something worthy of development. The fairly recent use of formal systems analysis, formulation of models, and more general use of data processing represent the application of new techniques permitting a degree of refinement in the solution of inherently complex problems. Such analysis is implicit in the planning and coordinated operation of the interrelated field of transportation, inventory control, and bulk supply. This operation is a sizeable activity as conducted within the framework of an integrated company organized into four major operating departments for—Producing, Manufacturing, Marketing, and Transportation.

This paper discusses the principal factors considered in optimizing a bulk petroleum product supply system. The situation assumed is a relatively simple one that serves to illustrate the various factors and how they are interrelated.

The problem for analysis is one of optimizing the system for maintaining an adequate supply of gasolines, jet fuel, and some kerosine and furnace oil, by sea lanes to four marine terminals in the same general section of the country. It should also be recognized that a solution usually represents a compromise between a theoretical target or long-run objective and the economic and operating realities of the present.

2—GENERALIZED ANALYSIS

The pure operations research analyst might well file an exception to the way in which the problem is stated, and rightly so. Several judgments or conclusions are implicit in the question as expressed. Why is the problem given the initial rigidities of using four terminals; why are the terminals restricted to the marine terminal category; why is there the limitation of considering only products rather than crude oil or semi-finished products? These, and a number of other valid questions would, in fact, be raised and answered. The disposition of many such questions becomes fairly obvious to one well-grounded in the specific field but, at the same time, there is an inherent danger that opinions will become set and the effect of changing times with new techniques and developments may not be recognized. Each of the above questions warrants an extensive discussion and explanation, but it will simply be assumed here that a careful consideration of all factors leads to a conclusion supporting the question as phrased.

The portion of the system discussed here has to be meshed into the total supply and transportation function. The supply and transportation operation, in turn, is integrated with marketing and manufacturing activities and these three functions are coordinated into the company-wide pursuit of corporate goals. The various factors are, in fact, interdependent.

The objective is to determine how the area should be supplied so as to meet minimum service requirements at optimum costs. Not expressed, because it is common to all bulk petroleum handling, is the qualification "with safety and in conformity with the requirements of regulatory authorities."

"Minimum service requirements" are interpreted broadly to mean maintaining a continuity of supply of products of the proper quality.

"Optimum costs" mean minimum total costs comprising a combination of fixed and variable expenses for transporting, handling, and holding.

What kind of marine transportation would serve these four harbors most economically? The choice would lie somewhere between single-port deliveries by ocean tanker and delivery by self-propelled or towed barge. The use of larger ships results in lower transportation costs with the differential cost advantage for size diminishing when the comparison is between extremely large ships. The paper presented to this forum last December by E. R. Weber of Esso Research and Engineering Company on the "Economics of Supertankers and Automation" is informative on this subject. The size of tankers assigned to specific services is affected by the physical limitations of water depths, anchorages, structures such as bridges constricting a waterway and other conditions affecting access to and maneuverability in the harbors under study. There is, then, an important category of technical matters which may be termed "Marine Operating and Engineering" matters and will not be dealt with here.

Conditions as they exist have to be recognized and for the harbors contemplated here general top limits varying from 30,000 DWT to 50,000 DWT are indicated. Single-port delivery of such cargoes connote an extremely large scale of operations which may not be attainable with present volumes of business. The possibility of further economy in delivery expense will be kept as an objective to be attained in future years. Let it be assumed that a 20,000 DWT tanker is indicated rather than something larger and that the quantities to be delivered, the considerable distances involved, and the nature of the sea routes preclude any serious consideration of delivery by barge. It is axiomatic that lowest transportation expenses are incured when delivery is on a full-load, single-port basis. The scale of operation assumed for the company in this illustrative case does not permit this. Thus, a series of constraints are introduced.

3—SHIP CONSTRAINTS

Although single-port discharge would be desirable as far as minimum transportation expense is concerned, this is not feasible at these four ports because the scale of operations creates a product quality restriction. Practically all of the product going to the four terminals in the example is motor fuel. There is a limitation on how long product can be held in storage and still give the customer the planned performance. The particularly limiting feature is the vapor pressure of the motor fuel. This is controlled so that the volatility will be appropriate to the climatic conditions under which automobile engines will be operating on the highways. The limitation is that the terminal inventories should not meet more than four to six weeks' demand depending on the season. Broadly speaking, then, the tanker should not deliver more than 12% of the year's requirement to a terminal at one time. It is revealing to see the effect that this limitation has in inducing increased delivery expense in excess of that for single-port deliveries.

Table I tabulates the transportation requirements to supply the stipulated volumes on a single-port basis to the four ports under study. Three factors are involved: (1) the volume to be delivered to each port, (2) the time required to make delivery, and (3) the size of the ship. The volumes to be delivered will be expressed in quantities expected to be shipped from the marine terminal each month during the year. There will also be a forecast of the expected annual gallonage over future years. This is usually estimated by the Marketing Department with the advice of the market research staff. For marine transportation purposes, these volumes will be translated into long tons for precise calculation of how much the ship will have to lift and into 42-gallon barrels for rough number calculations. In Table I, Column 2, the aggregate volume to be delivered to each port is indicated. The delivery time for a round trip voyage on a single port discharge is shown in Column 3. This is the representative elapsed time to load/travel to discharge port/discharge/return in ballast to loading port. The time taken to deliver each terminal's requirements is shown in Column 5. One way of showing this is by determining the daily delivery ability of the ship. This is the volume delivered divided by the days taken. Then, the daily ability is divided into the annual requirements of the terminal. For example, Port W requires 61.0 days per year of a 20,000 DWT ship's time and the four ports in aggregate require 121.3 days' ship time. This is time exclusive of average time for dry-dockings. To deliver the total four-terminal volume requires 17 voyages and arrivals a year.

The product quality limitation taken in conjunction with the scale of operations indicated by the terminal requirements necessitates the modification to

TABLE I

Column 1	2	3	4	5
	Annual Barrels	Days Single Port Delivery	20,000 DWT 160,000-Barrel Ship	
			Bbls./Days	Days
Port W	1,220,000	8	20,000	61.0
Port X	240,000	7	22,800	10.5
Port Y	420,000	7	22,800	18.4
Port Z	840,000	6	26,700	31.4
	2,720,000			121.3

$$\frac{2{,}720{,}000}{160{,}000} = 17 \text{ voyages and arrivals}$$

TABLE II

Column 1	2	3	4
	Annual Barrels	Peak Delivery	Rounded Top Volumes on Single Delivery
		@ 12% of Annual Barrels	Barrels
Port W	1,220,000	146,000	120,000
Port X	240,000	29,000	20,000
Port Y	420,000	50,000	40,000
Port Z	840,000	101,000	80,000
	2,640,000	326,000	260,000

maximum volume delivered at one time as indicated in Table II. The top volumes indicated in Table II, Column 3, should be delivered to the respective terminals only when inventories are at a minimum. If the inventories are not minimum, the quantity delivered should be reduced to compensate. Inspection of this data shows that no single port can be supplied a full load by the 160,000-barrel ship. It is evident that deliveries will have to be by some combination of two-port, three-port, and four-ports. This is necessary to maintain a continuity of supply at all ports. There will have to be some rounding of volumes delivered because of the size and multiples of the ship's cargo tanks. (See Column 4.)

The ship portion of the problem becomes one of finding the combination of deliveries that results in the lowest total expense for ship time, plus port charges. Table III represents the combination of ports and cargoes arrived at to deliver the specified total volume. There will be 17 voyages comprising 17 loadings and 53 discharges. Any other combination will incur expense for additional vessel days and additional port charges. This is to be avoided with port charges ranging from $800 to $1,400 per arrival and vessel days being worth $5,500 on this size ship.

TABLE III

Column 1	2 Arrivals	3 Port W	4 Port X	5 Port Y	6 Port Z	7 Days/ Voyage	8 Total Days
Total Requirements		1,220	240	420	840		
Maximum Delivery		120	30	40	80		
8 trips	32	70	30	40	20	12.3	98.4
2 trips	6	60		40	60	11.6	23.2
1 trip	3	60		20	80	11.6	11.6
6 trips	12	80			80	10.8	64.8
17 trips	53 arrivals						198.0 days

Volumes in thousands of barrels.

On the data developed thus far, we find that the product quality restriction results in our spending 76.7 more vessel days to deliver the annual requirements of the four terminals than if we had been able to deliver on a single-port basis. This represents $420,000 if we value the ship's time at $5,500/day. Split-port deliveries also result in 36 additional arrivals representing $36,000 at $1,000 per arrival. This is a total of $456,000.

Two parenthetical questions may be disposed of. Would it be cheaper to discharge a larger cargo at one of the ports and then trans-ship by barge to the next port? The barging cost is so expensive as to render this method unattractive. Would it be desirable to run the tanker with a short cargo and avoid going additional distance to a port to complete discharge of a relatively small quantity? There would be a breaking point indicating this decision, but in practice the incremental time and distance usually says to go ahead and utilize the full ship capacity.

Since the requirements of the four ports are less than a vessel's annual service time, the transportation requirements of this geographic region have to be integrated with other uses that will be made of the ship. This feature may have a bearing on preferences as to ship characteristics. A specialized ship for a specific trade may result in a ship lacking flexibility in total utilization. The ship may be uneconomic in general service. Therefore, the decision may be to have a high degree of uniformity in a fleet in the interest of overall best use of the fleet.

4—INVENTORY CONSTRAINTS

The amount of inventory and, hence, the money tied up in inventory will be related to the (1) size and frequency of deliveries, as just discussed, (2) variations in delivery time, (3) type of business handled from the terminals, (4) tank bottoms and operating considerations.

In our example, if Port X could have been supplied on a full-load basis, a delivery would have been required only every eight months. Then our average inventory would have been one-half the 160,000-barrel full cargo or 80,000 barrels rather than one-half of the 30,000-barrel cargo, 15,000 barrels as indicated because of the quality restriction. These averages would be over the allowances for the other three categories of factors indicated. This difference of 65,000 barrels at $4.00/barrel would be $260,000. The major part of the inventory factor, and one that is directly related to transportation considerations, is in the time between deliveries, the distance the ship travels, and the conditions to which the voyage is subject. In addition to the average delivery times it is prudent to stock some inventory against delays that may beset an individual voyage such as heavy weather or fog.

The short-term demand against a terminal may vary significantly from the average demand over an extended period. Product price fluctuations in the market may result in several days' demand being concentrated in a much shorter period. If spot sales are made from a terminal, this may increase the demand suddenly. Adequate recognition would be given these features and some protection would be provided by increasing inventories. The extent to which inventories will be increased to provide a flexibility to meet the vagaries of demand will represent a blend of experience, judgment, probabilities, taken with company policy and sobered by financial evaluations.

There will also be some permanent inventory attributable to physical considerations at the terminals. Tanks typically have some bottoms or "heels." Then, also, where floating roof tanks are used, and they are usual for gasoline storage, it may be desirable to maintain a designated footage of product in the tank to keep the roof floating and thereby minimize evaporation losses.

In the illustration used, the products are almost entirely motor fuels for current consumption. Therefore, the inventory problem is considerably less complicated than where heating oils are accumulated over several months for depletion in a fairly limited heavy consuming season of approximately 120 days. Inventory control of heating oil products would involve many additional considerations including refinery processing rates and the seasonal value of ships, just to mention two.

Enough has been presented to outline typical factors that are taken into consideration in planning terminal inventories. While these various factors have to be quantified, it would perhaps be proper to acknowledge that there is still room for a large measure of art as well as science in such calculations.

Table IV shows average inventories representative for the four ports in our example. These inventories recognize the further consideration that the demand rates for the individual grades vary and, hence, may "trigger'" a replenishment requirement if sufficient reserve has not been provided.

TABLE IV

Column 1 Terminal	2 Annual Throughput	3 Average Inventory
Port W	1,220,000 bbls.	100,000 bbls.
Port X	240,000 bbls.	60,000 bbls.
Port Y	420,000 bbls.	60,000 bbls.
Port Z	840,000 bbls.	50,000 bbls.
Total	2,720,000 bbls.	270,000 bbls.

5—TERMINAL CONSTRAINTS

A third and interrelated phase of a petroleum supply and transportation operation is the plant facilities. Broadly speaking, facilities would include the ships and possibly some portion of the tankage and wharves at the tanker origin. Discussion is restricted here to the bulk receipt and storage at the four tanker terminals to which deliveries are made.

The principal factors to be evaluated would be: (1) the maximum inventory to be held, (2) what provision should be made for the future, (3) what quality considerations are especially pertinent, (4) what ship unloading flow rates should be provided for, (5) what berthing facilities should be provided for present and future ships. These factors would be largely independent of the many features related to the outbound shipping of products.

The amount of tankage to be erected will be sufficient to handle the peak inventories that will be carried. This is derived from the analysis of reserve inventories, plus the expected maximum size of vessel deliveries and as affected by frequency of delivery. Obviously an even frequency of small deliveries will result in a lower peak inventory and, hence, required tankage will be less than needed to handle larger deliveries made less often. The capital tied up in tankage and incidental facilities may easily represent 50% more than the value of the average inventory carried in the tank.

The location and sizing of tanks, with probable future growth and changes in mind, may modify what would be done to meet a current or nearby requirement. For example, the compartmentation of future tankers might be changed with the consequence that the multiples to be handled on shore would change. It may be more economical in the long run to over-build at present than to have two separate building programs. This will be evaluated.

It may be that a product quality consideration, such as the need for settling jet fuel for a specified period before trans-shipment would indicate that two tanks will be required instead of one tank of equal capacity—which would be cheaper to erect. Having more than one tank in a product service will facilitate the changeover of stock when new specifications become effective for an improved product. Perhaps some closed system for vapor recovery is indicated to avoid the light ends being vented to the atmosphere.

The investment in unloading lines from dockside to terminal can represent a considerable sum, depending on the size of the pipe, its supports, route, and how far it is to the storage tanks. The number and diameter of the lines selected will be related to the volume and grades of product to be received, by the characteristics of the ship's cargo pumps and lines, and by marine conditions. The object is to minimize discharge time for the ship from "all fast" on arrival to "all free" on departure. The dominant factor may be the time between high waters if the ship's draft limits its maneuvering. It may be that travel through certain terminal approaches and docking and undocking would be carried out only during daylight hours. If, for example, the ship misses a tide, it will have lost half a day. The expected ship activity and the probability of conflict in use of the berths will also receive careful attention.

The physical characteristics of the wharf or pier, breasting clusters, bollards, and water depth at the berth will be governed by the size tankers to be used to supply the terminal. The facilities at a terminal receiving a part cargo have to be commensurate to the ship primarily rather than to the cargo volume. If it is expected that deeper draft tankers will be used, the dock should be built anticipating that there will be deeper dredging off the face. Many improvements planned by an individual company typically are coordinated with improvements undertaken by the Federal authorities who have the responsibility for maintaining and improving the nation's navigable waterways. The lead time between the recognition of need for a waterway improvement and final appropriation of funds by the Congress to enable the Army Engineers to let contracts may be several years.

6—SUMMARY

This paper has discussed in a broad manner the more significant factors considered in optimizing a selected portion of a bulk petroleum supply system. The factors are numerous, each has some affect on the others, the relative influence of each varies, the constraints imposed by each have some degree of flexibility.

The all-encompassing limitations would be those defined or implicit in company policies and goals. Then, there is the broad integration between the four major operating departments of an integrated company: Producing, Manufacturing, Marketing, Transportation. The next broad set of factors involves the selection of the transportation method. In the illustration discussed, the major interrelations are between three functions, tankers and their operation, inventories, and terminal facilities. There is further reconciliation and balancing of current operations with probable future development.

The selection of the appropriate ship involves many elements, some of which may be grouped as "Marine Operating and Engineering"—a whole field in itself—plus size, speed, pumping rates, interchangeability in service, specialization. The operation of the tanker in the assigned service will include attention to the sequence in which deliveries can be made to the ports under evaluation, how the use of the ship to the area studied can be integrated with the effective utilization of the ship to other areas, and the feature of quantity delivered. In the example, the limitation on the maximum cargo acceptable [illegible] each of the four points is a dominant factor.

Inventory plans include consideration of peak requirements, average requirements, size delivery, variations in demand, variations in replenishment schedules, and product quality consideration with this being a factor of extreme significance in our example.

At the terminals, the bulk product side of terminal planning and operation involves the peak tankage, the possibility of interchangeability of the service of tanks, forecast future growth, receiving lines and flow rates, quality considerations.

The complexity of the problem because of the number of factors and the need for making trade-offs between them, indicates that this is the kind of problem that is readily adaptable to formal operations research, simulation, and data processing treatments. At the same time, caution must be exercised in recognizing that quantification involves the exercise of judgment. The answers must stand the general test of reason. Then, there two specific tests.

One test is: What laid down bulk supply expenses at destination will the proposal give relative to estimated similar expenses for the most economic supplier in the area and for the "average" supplier in the area. The other test is after the fact: Did the proposal work satisfactorily?