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Contents

Authors of the Papers in This Record

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Assessing Waterborne Crude Oil Delivery Options

C. MICHAEL WALTON, MARK S. DASKIN, AND PRAMOD ATHALYE

The importance of waterborne delivery of crude oil, whether of foreign import or redistributed domestic, has become increasingly evident. Even with a stabilization of oil imports as mandated by the 1985 import ceiling of 8.5 million bbl/day or a decline in foreign imports, the redistribution of domestic oil from noncontiguous areas and territories, such as the Valdez port of the Alaskan oil fields, will most likely continue to increase. In addition, the ability of Gulf ports to process crude oil in a more cost-efficient manner, due to their extensive infrastructural capacity, will continue to attract foreign and redistributed domestic oil. In response to the increasing value of crude oil, cost-efficiency is necessary in every link of the shipping, distribution, redistribution, and transfer process of delivery. This paper, which focuses on one particular link in the process, has two primary objectives: (a) to review trends in lightering of crude oil from very large crude carriers by small tankers or lightering vessels off the Texas coast and investigate the characteristics of lightering operations based on present and projected conditions, and (b) to study and evaluate costs and environmental issues associated with lightering and two other options—an offshore deepwater port and an industry-proposed method of crude oil transfer. A brief review of waterborne crude oil delivery to the Texas Gulf Coast, a description of lightering operations, and a lightering model analysis with scenario applications are presented in pursuit of the first objective. The cost of transportation and adverse environmental impacts for each option are summarized in connection with the second objective.

With the ever-increasing cost of crude oil, and the related national as well as international ramifications, a variety of opportunities has surfaced. One opportunity concerns the trade-offs associated with the various options of delivering crude oil to the Texas Gulf Coast petrochemical plants. A study was initiated to review and evaluate the waterborne crude oil delivery systems off the Texas coast.

Specifically this paper describes two primary objectives of the study:

1. To review trends in lightering of crude oil from very large crude carriers (VLCCs) and ultra-large crude carriers (ULCCs) by smaller tankers or lightering vessels (LVs) off the Texas coast, and investigate the characteristics of lightering operations based on present and projected conditions; and
2. To evaluate costs and environmental issues associated with lightering and two other options--an offshore deepwater port and an industry-proposed method of crude oil transfer.

CRUDE OIL SUPPLY AND DEMAND

The United States is currently importing between 5 and 8 million bbl/day (MBD) of crude oil, mostly from distant sources such as the Persian Gulf and North and West Africa. The domestic production, which is steadily declining at a current estimated rate of 4 percent annually, translates into a growing concern over imported crude oil. A significant proportion of imported or redistributed domestic crude oil is destined for the ports in the Gulf of Mexico. At present, oil is brought to these ports either by transshipment at deepwater ports in the Caribbean or by lightering off the Gulf Coast. This is a necessity because the United States does not have a deepwater port capable of accommodating VLCCs that have drafts far in excess of the 45 ft associated with most U.S. port and harbor channels.

Another option is the transfer of crude oil at an offshore deepwater port from which the crude oil could be transported to onshore storage facilities through submerged pipelines. One such terminal, the Louisiana Offshore Oil Port (LOOP), is to be operational by mid-1981 off the Louisiana coast. Another similar facility, a Texas Deepwater Port (1), has been proposed for location off Freeport (see Figure 1).

It is likely that the demand for crude oil will be reflected in increased lightering activity. This will necessitate regulation of lightering procedures that are being proposed to ensure safety and environmental standards.

LIGHTERING

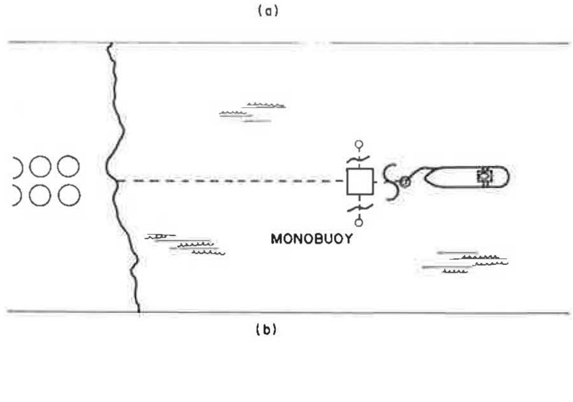
Approximately 2.2 MBD of waterborne crude oil were delivered to the seven major Texas Gulf ports in 1978. Thirty-six percent of this volume (0.8 MBD) was lightered from VLCCs with most of the remaining transshipped from Caribbean ports. Data show an increasing recent trend in lightering activity (1).

Lightering Zones

Location criteria for a lightering zone include cost efficiency and maximum environmental safety. Unfortunately, these two criteria are not always compatible and require a compromise. With respect to environmental safety, two primary factors are distance from shore and remoteness from submerged reef structures that exist in the Gulf off the coast of Texas. Distance from shore is the most important factor to consider as it determines, in large measure, the time required for a spill to reach the shoreline. The longer crude oil "weathers", the less toxic it becomes. Based on estimated average speed of an oil slick and time required for crude oil to lose its toxicity, lightering zones are preferred to be located at least 25-30 miles offshore and desirably 50-60 miles. Excessive distances, however, can hinder the on-site arrival time of additional shore-based spill control equipment.

A primary location cost consideration is minimizing travel time between the zone and port. The

Figure 1. A sketch of an offshore deepwater port.



total turnaround time for LVs is a major concern in reducing transportation costs. This suggests that zones should be located as close to the ports as possible. For the Texas Coast, the 100-ft depth lines run 20-30 miles offshore. Therefore, lightering zones should not be closer than 40 miles off the coast of Texas, centrally located to serve several ports, away from major shipping lanes, and remotely located from offshore reef structures.

Fleet Characteristics

Most VLCCs are owned by the major oil companies or their subsidiaries. For the purpose of this study, these vessels were estimated to have an average deadweight tonnage (DWT) of 250 000. The normal turnaround time between the Persian Gulf area and the Gulf region is approximately 60 days. At present the relative charter costs of VLCCs as compared with LVs is quite low. The LVs are either owned by the oil companies or by small, local shipping lines that operate, lease, or charter these vessels. Their average cargo-handling capacity is about 50 000 DWT, which requires a draft of about 35-45 ft when loaded. Unlike VLCCs, these vessels tend to be relatively old (15-20 years).

Regulations and Safety

The U.S. Coast Guard has proposed safety regulations and standards for lightering operations and associated equipment (1). Objectives, among others, were to minimize the probability of an oil spill that might be caused by the use of substandard equipment or hazardous operating conditions, as well as to develop procedures that would facilitate the control of an oil spill should one occur. The presence of oil spill recovery vessels, related equipment, and personnel is deemed essential for any lightering activity. Except for spills that result from ship collisions or accidents unrelated to operations conducted during the transfer of crude oil, no major oil spills to date have been attributed to lightering operations.

Operational Aspects

Lightering operations are normally conducted with both vessels moving parallel to one another, at low speed, and with an initial minimum separation of 200-300 ft. Gradually the vessels are brought closer to each other until the forward primary fender of the LV makes contact with the hull of the VLCC (see Figure 2).

Although there are no specified offshore lightering zones, most of the lightering occurs in four locations. These zones were enumerated and appropriately plotted on the coastal map (Figure 3) for use in the analysis of lightering operations.

ANALYSIS OF LIGHTERING OPERATIONS

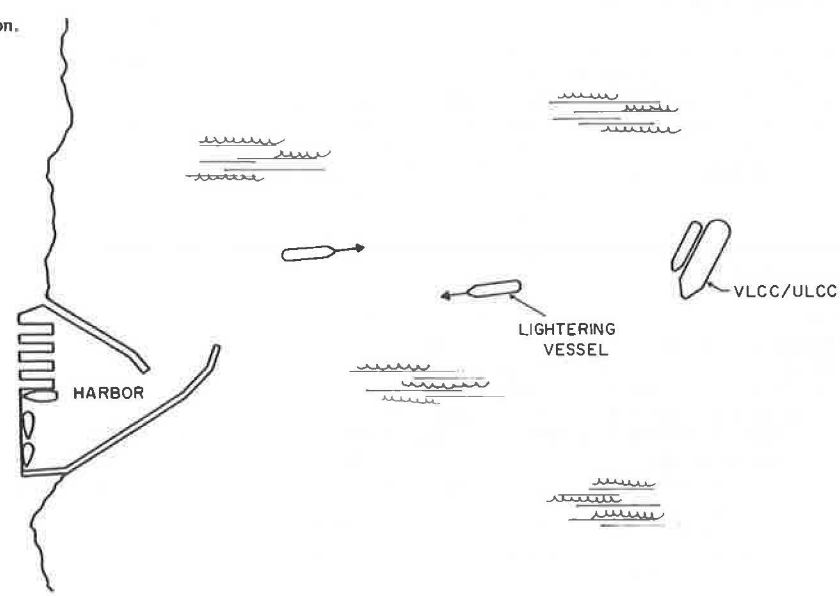
Considering the increasing importance of lightering, an analysis procedure was developed to minimize overall cost ($/bbl) through the reduction of operating delays, number of LVs deployed, and other related factors. Analytical constraints include the amount of crude oil brought into the Texas Gulf region and the location of lightering zones and ports.

A linked queuing model of lightering operations (2) was developed and used for the analysis. The model is depicted in a lightering operations schematic (Figure 4), which shows two VLCCs being served (lightered) in the zone, one VLCC waiting, 13 LVs shuttling between the zone, and a three-berth port. This depicts one particular "state" of the given lightering operation, which is characterized by the number of VLCCs in the system being served and waiting, and the LVs in the system. LVs can be in one of six possible conditions; (a) serving a VLCC, (b) in transit to the port, (c) waiting to unload at the port, (d) unloading at the port, (e) in transit to the zone, and (f) waiting to load at the zone.

The state of the system changes according to the arrival and departure time of VLCCs and the shuttling of LVs between the zone and the port. By determining the long-run average probability of all possible states of the system (the steady-state probabilities), the average operating conditions for a given lightering configuration can be obtained. This includes VLCC and LV delays and the use level of the berths in port.

The linked queuing model consists of two submodels, the LV movement model and the VLCC delay model, linked through a third model of VLCC service time (2). Figure 5 is a macro flowchart of the model system. Inherent in these submodels are assumptions based on the following elementary economic

Figure 2. A sketch of a typical lightering operation.



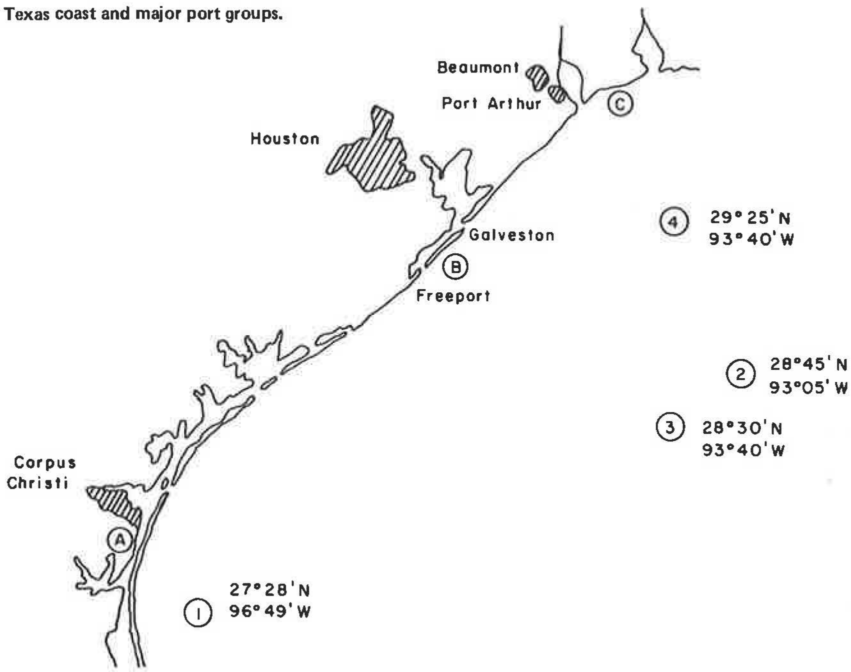


Figure 3. Current lightering areas along the Texas coast and major port groups.

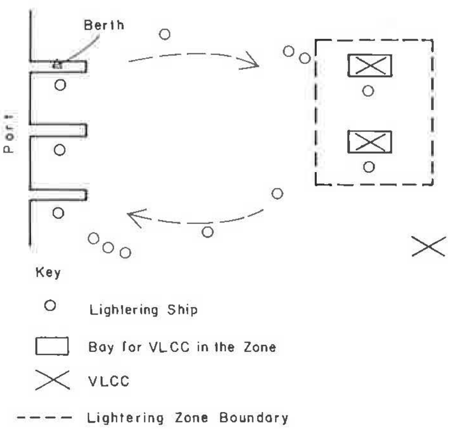


Figure 4. Schematic of lightering operations.

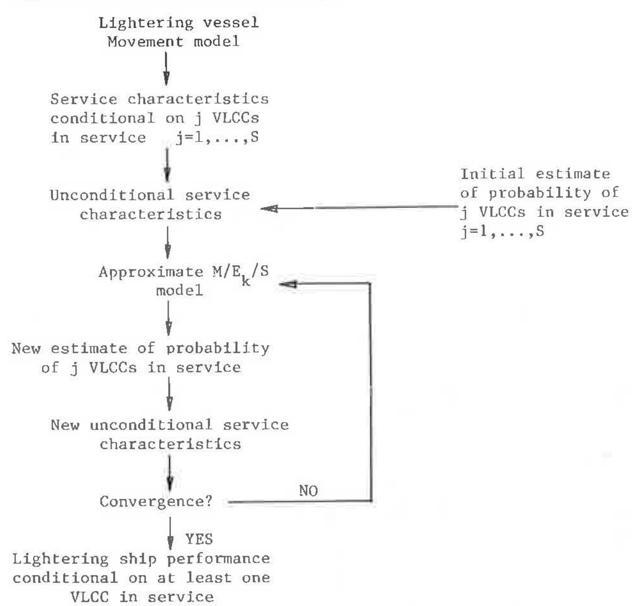


Figure 5. Macro flow chart of model system.

considerations: (a) The number of berths in the port should not exceed the number of LVs and (b) the number of VLCCs that can be simultaneously served should not exceed the number of LVs deployed. The three submodels are briefly described below.

Lightering Vessel Movement Model

A cyclic queuing model developed by Gordon and Newell (3) has been used to describe LV movements, conditional on at least one VLCC in service. The model has also been used by Koenigsburg and Lamin in a study of transoceanic ship movements (4).

LV movements are divided into four components: loading at the zone, travel to the port, unloading at the port, and travel to the zone. Possible delays are assumed during the loading and unloading components. The loading, unloading, and shuttle times between the zone and the port are assumed to be exponentially distributed, independent, random variables.

For a given number of LVs and a given number of LVCCs in service, the model determines the probability of finding j LVs in each component, for all possible values of j. The number of LVs in each component summed over all components must equal the number of LVs deployed for each state of the system. The model obtains, in particular, the probabilities of j LVs loading or waiting to load. These probabilities are used in the VLCC service time model. The LV model is solved for all possible numbers of VLCCs--from one to the maximum that can be served simultaneously.

VLCC Delay Model

An approximate model of an M/E$_k$/S finite queuing system was developed to estimate VLCC delays. The model assumes that VLCC arrivals follow a Poisson distribution, service times follow an Erlang-k distribution, and a maximum of 30 VLCCs can queue for service.

The model estimates queue lengths and delays for a given service time distribution. The probability of j VLCCs in service, for j = 1...S, is also given. These results are conditional on a given service time distribution.

It is assumed that, if service times are described by an Erlang-k distribution, each VLCC brings with it k units of work, and each of these units requires an independent, exponentially distributed period of time for completion (5). Instead of accounting explicitly for the remaining work units at the end of service at each of the servers, as an exact model would entail, the approximation is based on the total number of work units in the system. According to some preliminary tests, the model slightly underestimates the total times in the system. Daskin and Walton (2) are pursuing refined approximations. The model is exact if the service times are exponential or if there is only one VLCC bay in the lightering zones.

VLCC Service Time Model

The VLCC service time model consists of two parts. The first determines the mean and variance of the service times, conditional on a given number of VLCCs in operation. The probability of finding j lightering ships at the zone, conditional on a given number of VLCCs in service, is employed. These probabilities are determined by the LV movement model.

The second part of the model computes the unconditional mean and variance of VLCC service times. The probability distribution of the number of VLCCs in service, derived from the VLCC delay model, is employed to obtain the unconditional mean. Since this delay model depends on the service time distribution, which, in turn, depends on the output of the delay model, the two models must be solved iteratively until they converge to a common service time distribution. This process is initiated by assuming that the distribution of the number of VLCCs in service corresponds with a finite queue M/M/S system with state-dependent service time durations.

The model converges when k, the shape parameter of the service time distribution, is not altered from one iteration to the next and when the percentage of change in the mean service time is less than a user-specified value, h. For a low h value of 0.01, the model has never required more than 11 iterations.

Once the model has converged, the probability distributions of LV movements, conditional on a given number of VLCCs in operation, are combined with the VLCC delay model approximation of the probability distribution of the number of VLCCs in service. This gives an estimate of the number of LVs in each of the four components mentioned earlier, conditional on at least one VLCC in service. The model inputs appear in the table below:

Input Type	Description
Primary	Number of lightering vessels
	Number of berths in port
	Number of VLCC/ULCCs that can be served simultaneously
Secondary	Arrival rate of VLCC/ULCCs
	Size of lightering vessels
	Distribution of VLCC/ULCC sizes
	Mean loading and unloading times for lightering ships
	Mean travel times for lightering ships to and from port
Model control	Iteration limit
	Convergence criterion

The model outputs are given in the following table:

Output Type	Description
VLCC/ULCC	Mean and variance of number in system and in queue
	Mean service, queuing, and system times
	Estimated state probabilities
Lightering vessel	Mean and variance of number of lightering vessels in each of four components
	Mean and variance of number of lightering vessels delayed loading and unloading, given at least one VLCC/ULCC in service
	Distribution of all possible numbers of lightering vessels in each component, given j VLCCs in service, j = 1,...,S

Model Uses and Analysis

The linked queuing model was used for an analysis of lightering operations for the following scenarios: current lightering operation, lightering with the minimum shuttle time between a current lightering zone and port (minimum time), future lightering operation with a ceiling of 8.5 MBD on imported oil (through the year 2010), and future lightering operation without restrictions on volume of imported oil.

The model results were used to estimate costs associated with a lightering operation. These durations are sensitive to mean arrival rate of VLCCs, service time durations of LVs, and number of LVs.

Since VLCC arrivals in the Gulf region are nonscheduled (assumed to follow a Poisson distribution in the model), no control, other than diverting a VLCC to another lightering zone, can be exercised over arrival rates to alter lightering operations.

Given the four general offshore lightering locations, a relatively constant shuttle time between these zones and the ports has been established. There is also little variability in the loading and off-loading time of crude oil, which is a function of the equipment used. Therefore, the variable that can be employed to control an operation is the number of LVs used.

The ports segmented into three groups to reduce the number of computer runs of the model. The port groups appear below:

Port	Port Group
Corpus Christi	A
Freeport, Houston, Galveston	B
Beaumont, Port Arthur-Lake Charles	C

The model inputs for each operational case were derived according to the procedures described below.

Current Lightering Operations

A direct comparison can be made regarding the operational characteristics between port groups and zones if the number of VLCC bays in a lightering zone is held constant. One VLCC bay was considered.

The number of berths available in port was assumed to be sufficient for the operations (i.e., equal to the number of lightering vessels). This assures no waiting time in the port.

Table 1 lists the destination and volume of crude oil lightered in each zone. The arrival rates of VLCCs for each zone and port group were computed by using the volume of crude oil lightered during the period January-June 1978. The results are listed in Table 2.

Table 1. Total tonnage per lightering zone.

Port Group	Port	Lightering Zones: 27°28′ N, 96°49′ W (1)	28°45′ N, 93°05′ W (2)	28°30′ N, 93°40′ W (3)	29°25′ N, 93°40′ W (4)
A	Corpus Christi	2 007 800	-	430 000	-
B	Freeport, Galveston, and Houston	61 400	1 245 609	6 660 809	-
C	Lake Charles and Port Arthur-Beaumont	-	35 220	7 547 851	145 330
Total (January-June 1978)		2 069 200	1 280 829	14 638 660	145 330

Table 2. Current VLCC arrival rates (ships/h).

Port Group	Lightering Zone 1	2	3	4	LV DWT at Each Port Group
A	0.002 10	-	0.004 5	-	55 000
B	0.000 06	0.001 3	0.006 97	-	50 000
C	-	0.000 04	0.007 9	0.0015	47 000

Table 3. Estimated shuttle time for lightering vessels between various lightering areas and port groups.

Port Group	Shuttle Time[a] (h): Zone 1	Zone 2	Zone 3	Zone 4
A	8.6	49.3	42.9	46.1
B	32.1	21.4	17.9	13.2
C	43.9	14.3	15.0	6.8

Note: Possible error of ±20 miles between port groups and lightering zones.

[a]Based on an overall speed of 5 knots/h.

Figure 6. An example of VLCC waiting and service time durations (assuming port group A, Zone 1, with 1 VLCC bay).

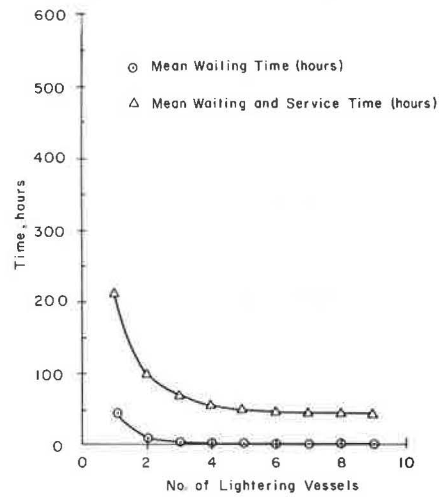
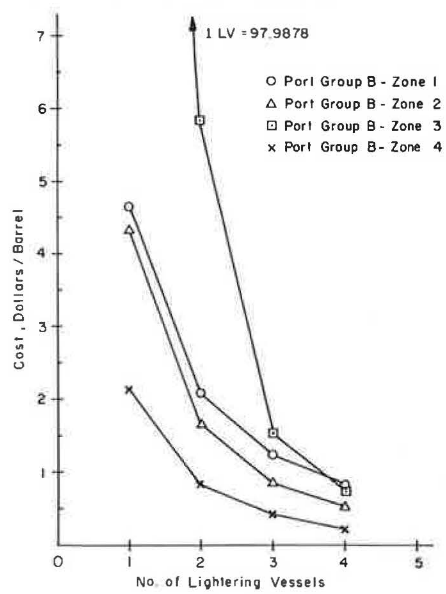


Figure 7. Lightering cost, port group B.



Lightering Under Minimum Shuttle Time

Minimum time refers to the shuttle time between a port group and the nearest lightering zone. The matrix (Table 3) shows that zones 1, 4, and 4 are the nearest to port groups A, B, and C, respectively. The model runs were computed with the assumption that all the crude oil lightered in different zones and destined for a port group was lightered in the nearest zone.

Future Lightering Operations

The year 2010 was chosen as the analysis horizon. Two scenarios were considered under this case: (a) restriction of crude oil import by a ceiling of 8.5 MBD and (b) no import restrictions.

The key simplifying assumption in this case was that the share of crude oil transshipped in 1978 would remain constant through 2010. The average VLCC/ULCC DWT was increased to 350 000 to reflect the growing size of these vessels. Most of the remaining assumptions such as LV DWT were assumed to remain constant (50 000 DWT).

Figure 6 represents an example of waiting and service time durations of VLCCs and LVs, given a varying number of LVs servicing one VLCC. Beyond a certain number of LVs, the waiting and service time durations for a given arrival rate of VLCCs are not reduced appreciably. There is a trade-off between these durations (costs of operating and delay) and the number of LVs deployed.

Figure 7 is an example of estimated total lightering cost versus the number of LVs deployed by lightering zone. These suggest that beyond the use of three LVs, there is no significant reduction in costs. The number of LVs that yields minimum cost is a function of a given VLCC arrival rate, the mean number of LVs at the zone (waiting to lighter), and the probability of LV delay. The LV delay increases with an increase in the number of LVs. The duration of this delay cannot be estimated from this model as

Figure 8. Total lightering cost, restricted import case.

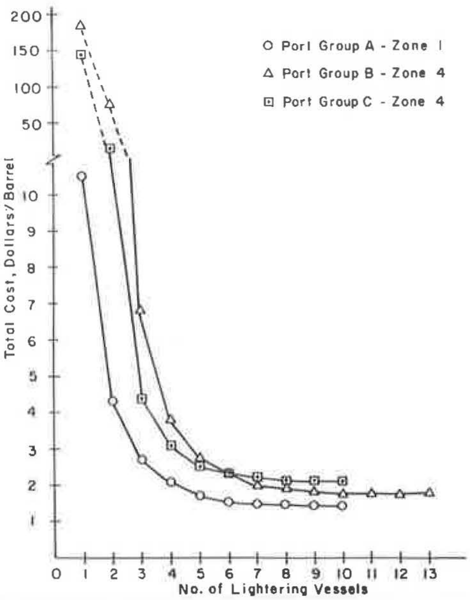
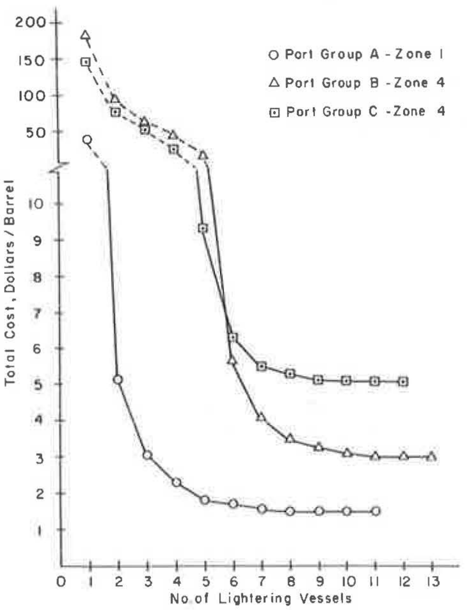


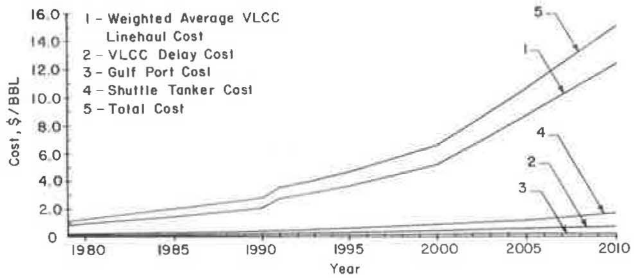
Figure 9. Total lightering cost, unrestricted imports.



it is currently designed. Recent extensions to this model and the development of alternate lightering models allow estimation of this delay. Second, there is also the possibility of port delay because of a nonavailability of berths, although a sufficient number of berths for a lightering operation have been assumed in the model runs. A more realistic inference is that three LVs would be appropriate. Figure 8 shows the total lightering cost estimated for the import restricted case by port group and closest lightering zone.

Next, the model computed the results for lightering operations under the no-restriction case. Runs with one VLCC bay in a lightering zone revealed relatively high values of waiting and service times for the arrival rates corresponding to zone 4. Figure 9 shows the total lightering costs.

Figure 10. Lightering costs (distant sources), 1979-2010.



It may be inferred that having more bays reduces the waiting time durations of VLCCs but increases the service time durations in some instances. An optimization of total lightering costs associated with these durations would indicate the optimum lightering conditions. The results obtained from this approach suggest that the use of such a model can provide insight into the operational aspects of lightering activities. It should be emphasized that the results discussed above are tentative and suggestive in that the models used are all conceptual and preliminary. The inferences derived from the model output were used in the cost analysis.

CRUDE OIL TRANSPORTATION COST ANALYSIS

The cost analysis focused on the per-barrel transportation cost of oil delivered to the Texas Gulf Coast processing centers from 1980 to 2010. For this cost analysis, only crude oil transfers from the Arabian Gulf and North and West Africa were used. Mexico was treated separately. The three options evaluated are defined as lightering, an offshore deep-water port, and an industry proposed lightering system.

Lightering

In the analysis of lightering the following cost categories were included: shuttle tanker transportation cost, Gulf port charges, VLCC/ULCC delay cost, and VLCC/ULCC line-haul cost.

A summary of lightering costs from 1980 to 2010 is shown in Figure 10 (1). Line-haul costs were separately computed for the Persian Gulf, North Africa, and West Africa and then a weighted average of line-haul cost, based on the expected volume of oil from each of these sources (Persian Gulf, 70 percent; North Africa, 2 percent; and West Africa, 28 percent), was calculated.

Offshore Deepwater Port

The state of Texas and others have explored the feasibility of constructing a deepwater port off the Texas coast. This port requires construction of an offshore platform, monobuoys, terminal-to-shore pipelines, and onshore storage facilities. In addition, construction of new pipelines, connecting the onshore storage with various refineries along the coast, would be necessary. The two primary cost items of this option are a deepwater port tariff and a pipeline tariff.

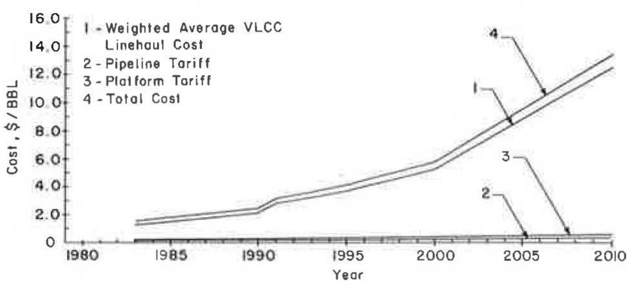
A summary of costs for the deepwater port (1983-2010) is shown in Figure 11 (1). Line-haul costs were slightly higher for the deepwater port than for a lightering system.

Industry-Proposed Lightering System

The industry-proposed lightering system is a combination of various transshipping, lightering, and offshore monobuoy system characteristics. It would involve a smaller initial cost than an offshore port but a higher operating cost. The cost items for this option (assuming that VLCC delay costs are effectively reduced to zero) are (a) tariff (includes the cost incurred due to mooring ULCC at the platform or monobuoy), (b) shuttle tanker transportation cost, (c) Gulf port charges, and (d) VLCC/ULCC line-haul cost. The cost categories for these options are summarized in Table 4.

This operation, shown in Figure 12, uses an ULCC permanently moored offshore served by VLCCs arriving from distant sources in transferring the crude oil. LVs in turn transfer this crude oil from the ULCC to port. This scheme aims to reduce the delay and, hence, the cost of VLCCs. The transportation costs for the industry proposal are shown in Figure 13. Because the industry proposal analysis used Corpus Christi costs, both line-haul and port-shuttle tanker costs are different from the lightering costs.

Figure 11. Offshore deepwater port costs (distant sources), 1983-2010.



Comparison of Various Import Methods

Figure 14 shows the total costs of the three import methods for 1980-2010. The offshore deepwater port is shown to have a slight cost advantage over the other two options.

ENVIRONMENTAL CONSIDERATIONS OF TRANSSHIPMENT

Crude oil is a complex mixture of hydrocarbons and organic compounds, including sulfur, nitrogen, and oxygen. The hydrocarbons are mostly toxic. Because oil possesses a lower specific gravity than water, it tends to remain on the surface and spread when spilled. Wind and water currents are primarily responsible for directing the drift of an oil slick and its determining rate of spread on the surface.

Once the highly volatile, toxic fractions are exposed to the air and water, they dissipate rapidly due to evaporation, solution, emulsification, and precipitation. This process is known as "weathering." The weathering rate is highly dependent on the type of oil, climate conditions, and sea conditions. Evaporation is most crucial in the early stages of a spill because it involves the most highly toxic and volatile components. The majority of the toxic components dissipate in the first 24-36 h.

The location of an oil spill relative to biologically sensitive environment is perhaps the most crucial determinant of the ecological impact of an oil spill. In Texas, an offshore spill is generally less environmentally damaging than one that occurs with the bays. Most biologically sensitive plant and animal life is sheltered from the open sea by the barrier island and, in the event of an oil spill, their protection would be relatively easy.

Oil pollution damages occur immediately and have

Table 4. Cost items associated with various means of crude oil transshipment.

Item	VLCC/ULCC Line-Haul Costs	VLCC/ULCC Delay Costs	Pipeline Tariffs	Gulf Port Charges	Shuttle-Tanker Costs	Platform (Facility) Tariffs
Lightering	√	√		√	√	
Texas deepwater port	√		√			√
Industry-proposed lightering system	√			√	√	√

Figure 12. A sketch of industry-proposed lightering.

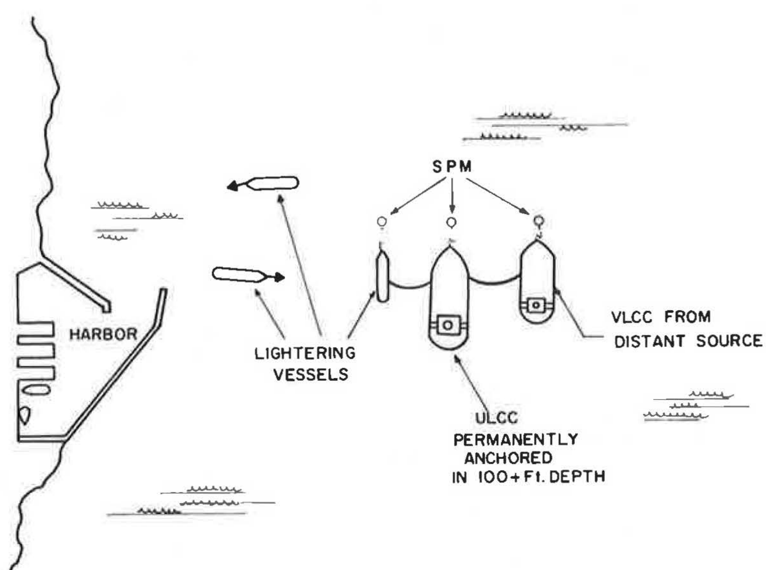


Figure 13. Industry-proposed lightering system costs (distant sources, 1981-2010.

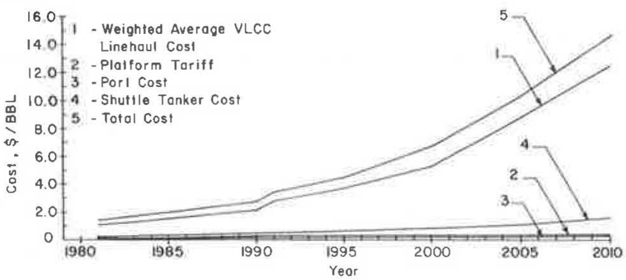
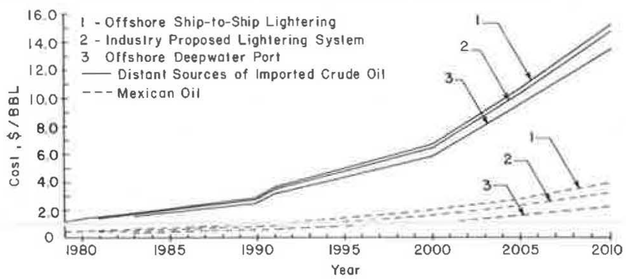


Figure 14. Cost comparison of various import methods, 1980-2010.



long-lasting effects, although the recovery of most living systems is usually rapid and complete. Short-term damages are easier to assess than long-term, in which no evidence is seen for several months or even years following an accident.

It should be noted that apart from crude oil, many chemicals, dispersants, solvents, and cleaners used in spill clean-up operations can cause more damage than naturally degrading oil.

The potential impact associated with each method of transshipment was estimated on the basis of the environmental and economic effects of oil spills. The impact potential is a combination of spill probabilities and possible exposure to critical habitats. Spill probabilities are based on the complexity of operations, both human and mechanical. These complexities include spills that occur from cargo exchange, ship collision, or pipeline failure. Exposures to critical habitats were determined by noting the location of potential spills, according to each type of operation, and comparing them with the location of critical habitats. Spill control response to these locations was considered.

CONCLUSIONS AND COMPARISONS

Lightering

Present delivery methods include unrestricted lightering (ship-to-ship transfer) in Texas offshore waters and Caribbean transshipment. Both methods at present require the entrance of oil-carrying vessels into Texas bay systems to reach the port and refinery facilities.

Approximately five lightering operations may be necessary to unload each VLCC that yields as many as 10 cargo transfers. Statistics indicate that human error and mechanical failure are the primary causes of oil spills (1). For example, the spill frequency for lightering is about 12.1×10^{-3} spills/transfer operation, while the magnitude of potential spills averages about 2.32×10^{-6} units spilled/units transferred (6). The average operational spill, associated with mechanical failure or human error during cargo transfer, either at sea or in port, is approximately 238 bbl. The estimated average size spill, resulting from a minor VLCC collision, is approximately 2400 bbl, while a major VLCC accident spills approximately 112 000 bbl. A spill that results from the grounding or collision of a lightering vessel (possibly within the bays) can approach 95 000 bbl (1).

The most important environmental safety consideration is the entrance of lightering ships into bay systems along the major deep-draft inshore channels. These channels and associated passes are heavily traveled by other types of shipping. Forecasts of other types of shipping and oil importation indicate that the number of lightering ships will also increase, which suggests increased congestion of the ports, waterways, and fairway anchorages. Many lightering ships lack modern navigational equipment, further increasing the possibility of an accident.

The above considerations are significant, not only in terms of the increased risk of collisions or grounding, but also because the resulting spills are close to critical habitats. Nearly all inshore shipping channels involved in the transportation of petroleum products pass near or directly through critical habitat areas. If a spill occurs in these areas, little or no time will be available for weathering, containment, or exclusion procedures; this will result in possible severe environmental damage and economic ramifications.

A lightering-related spill that occurs in offshore waters would have a minimal environmental impact because there would be sufficient time for weathering and enactment of exclusion procedures. Possible exceptions to these safeguards occur in the instances of extremely large spills, tanker collisions just outside major passes, or tropical storms, generating large waves that carry oil past the exclusion booms into the bay areas.

Spill control response is generally slow or nonexistent in current lightering operations except in some spill-equipped port areas. In one case, a major shipping company supplies its own tender vessel to each lightering operation. Today, private shipping companies have the complete responsibility to report spills, establish safety methods, and maintain the proper equipment.

Proposed Offshore Deepwater Port

From consideration of the economic and environmental aspects of these options, the offshore deepwater port was found to be most desirable. Only one cargo transfer operation is necessary per VLCC at an offshore monobuoy. The oil would then be pumped to onshore storage or refinery facilities at Freeport through submerged pipelines. The potential occurrence of operational spills is therefore restricted to the offshore location where environmental impact potential is the lowest. In addition, the oil comes ashore at only one location along the coast and that location can be chosen as to eliminate any direct contact with a critical habitat area.

Spill probabilities are also reduced due to the increased simplicity and control of operations. The average size of a spill resulting from a VLCC accident is the same as a spill from a lightering accident. The average spill size from a pipeline rupture would be 19 bbl with a credible maximum of 10 000 bbl based on the engineering design features of a 52-in pipeline with pressure sensing, loss-metering system, and the ability to induce some suction on rupture lines (1). The average operational spill that occurs at the off-shore site would be 15 bbl, while spills from offshore and onshore terminal facilities would average 19 bbl.

Summary

Unrestricted lightering, as it occurs today, has the highest risk potential, mainly due to the operational complexity and the high exposure to critical habitats at numerous locations along the coast. The calculation of spill probabilities for lightering have yielded results that are 60 percent higher than methods employed in operations of an offshore port. With the opening of LOOP, the United States will have its first offshore port and a laboratory for further observation and study. The ultimate assessment of the utility of offshore deepwater ports awaits the operational experience of this facility.

ACKNOWLEDGMENT

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Application of Freight Network Model to Coal Transportation Studies

ARTHUR F. HAWNN, FRANCIS M. SHARP, MARK VEITH, MARK SILVERMAN, AND MARK COHN

This paper examines the transportation freight model (TFM) developed by the U.S. Army Corps of Engineers. The focus is on coal movement on inland waterways. TFM is a simulation model to assess the interregional modal share of commodity movement, waterway link capacity, and performance characteristics. TFM consists of a transportation network of links and modes (water, rail, highway), performance functions, cost-capacity functions, transport technology, transportation market equilibrium, network adjustment, and commodity flow input. Commodity input was categorized in two groups—coal and all other commodities for 1972 and 1976. Simulation and validation results were compared with actual values in terms of such parameters as total tons, ton miles, mills per ton, average length of haul, and water-rail modal splits. These comparisons indicate that TFM can be used for macroanalysis of waterway commodity flow analysis.

Coal has been designated as the keystone of the U.S. fuel supply for the future because it is a domestic fuel source in abundant supply. The economic impact and competitiveness of increased coal use in industry and electric power generation are determined in large part by the delivered price of coal. A significant component of the delivered price of coal is the transportation margin. For example, the cost of delivery of coal via rail frequently is 30 percent or more of the delivered price of coal. Consequently, coal consumption forecasts should be based on transportation cost data consistent with the market.

Conversely, transportation costs are a function, in part, of the quantity of coal shipped. Specific plans for capital plant, e.g., rail lines and navigational facilities, are cost-justifiable only with traffic volumes above certain minimums. Representation of the partial equilibria (coal demand on transportation cost and transportation costs/constraints on demand for coal) and the equilibrium adjustment mechanism (the transportation market) are elements of a transportation market analysis.

Development of forecasting models with intensive data requirements is a difficult task. However, significant research and development have occurred in this analytic arena. Prudent linking of existing modules may provide significant capability for prediction of coal transportation margins and coal shipments for given macroscenarios.

Under the U.S. Army Corps of Engineers Inland Navigation Systems Analysis (INSA) program, the Office of the Chief of Engineers (OCE) developed the transportation freight model (TFM), a multimodal, bulk-commodity simulation. To meet the national requirement for detailed coal transportation analysis, the OCE and CEXEC, Inc., of McLean, Virginia, initiated a project to evaluate the TFM in light of OCE needs for detailed local traffic analyses and national needs to enhance coal-market policy analysis tools.

STUDY OVERVIEW

The objective of the study documented in this paper is to assess the applicability of the TFM to coal transportation studies. These objectives are

1. To ensure the input data and the model logic to be internally consistent and output results to

reflect sufficient confidence to enable forecasting and scenario analyses of the transportation network,

2. To validate the results of the model to be sufficiently accurate to enable policy and forecasts of more general commodity markets,

3. To determine the results of the model to be of sufficient detail and confidence to provide control sums for detailed waterway traffic studies, and

4. To improve the performance and data base of the model.

By establishing that the input data for a given baseline are reasonable and that the model represents the transportation in a logical, consistent manner, desired studies may be developed.

Methodology

The first step entailed adjusting the 1972 dollar values to 1976 values. This step was required to enable comparison of estimated transportation costs with 1976 baselines values. Update parameters were estimated by mode, by region, and for specific parts of each network.

The TFM input was adjusted for changes in the coal regionalization scheme. Access links were reallocated as required by the new regions. Output from the TFM was compared with transportation industry statistics and coal mode splits available from the U.S. Department of Energy's (DOE's) Coal Distribution System. Modal splits, tons, and ton miles were evaluated statistically and on an individual basis by transportation analysts. Total system data were studied first; where systemwide bias was identified, relevant input data were reviewed and adjusted. Finally, individual origin-destination (O-D) pairs were studied to identify regional or specific bias. When the modal tests reached the point where results were as accurate as it appeared the model was going to achieve, cost tests were applied.

Several primary data sources were used to provide baseline comparison data. The Transportation Association of America (TAA) was the source of total tons, ton miles, and cost by rail and water. Since the model estimates intraregional flows only, some differences existed with comparison data. DOE source data (1) on coal shipments by mode and O-D pair served as the primary information. These data are considered to be accurate by virtue of several validation tests.

TFM Background

The background of the INSA program is discussed by Sharp, Hawnn, and others (2) and the specific development of the TFM is described by Bronzini and Veith (3). The model has been applied in several federal policy studies including (a) the 1976 Corps of Engineers waterway user charge study, (b) the U.S. Geological Survey's analyses of western coal markets, and (c) the national energy transportation study.

MODEL OVERVIEW

The multimode network model evolved as a result of recognition that the inland waterways had to be analyzed as a system, not as a series of individual projects, and that the waterway system had to be studied in the full context of intermodal competition. Thus, the multimode network model enables the simulation of shipper behavior, given the cost and capacity attributes of alternatives mode networks.

The first application of the model was in 1976 in which water and rail networks were simulated. Successive development sponsored by the Transportation Systems Center (Cambridge, Massachusetts) has augmented the network simulation with highway and pipeline modes.

Each network is represented by line-haul links, nodes, and access links, which are connected by intermodal transfer links. The links and nodes are classified by performance characteristics. Link and node class performance is represented by fully allocated cost functions and capacity functions relating shipping cost and time to annual volume. Resident within the model is a data base of cost and capacity function parameters.

Commodity specific O-D shipment vectors are given. Average value and inventory sensitivity are the commodity attributes used to simulate shipper behavior with respect to shipment delay. Shipments are routed on mode routes that would be perceived as a minimum cost and time path by shippers subject to the initial effects of long-term contracting and institutional commitments. Allowable path choice is constrained by limiting route circuity to an ellipse with foci at the origin and destination. Also, selected routes may be specified for shipments, and historical patterns may be reinforced by imposing enhanced inertia on the mode choice or route selection options for a sector, commodity, or O-D pair.

The least-cost path logic begins with the definition of the path cost. Path costs are a sum of shipping costs over each element in the path (nodes, line-haul, and access and transfer links) and inventory cost. Element costs and travel times are nonlinear functions of the volume of traffic. Initial volume estimates are assigned to all network elements to permit calculation of costs and travel times for early shipment. Selection of a minimum cost path by a shipment alters the volume travel time and the cost for successive shipments. The final volumes simulated are used as initial volume estimates for the next iteration. The model reiterates until the tested convergence is at an acceptable tolerance.

ANALYSIS

The TFM performance will be reviewed in terms of predictive capability in relation to actual reported shipping statistics and in terms of the model's internal consistency. A top-down hierarchical approach has been employed:

1. National shipment characteristics for all commodities to national figures for coal shipments,
2. Regional characteristics for both terminating and originating shipments, and
3. Shipments between particular origins and destinations (O-D pairs).

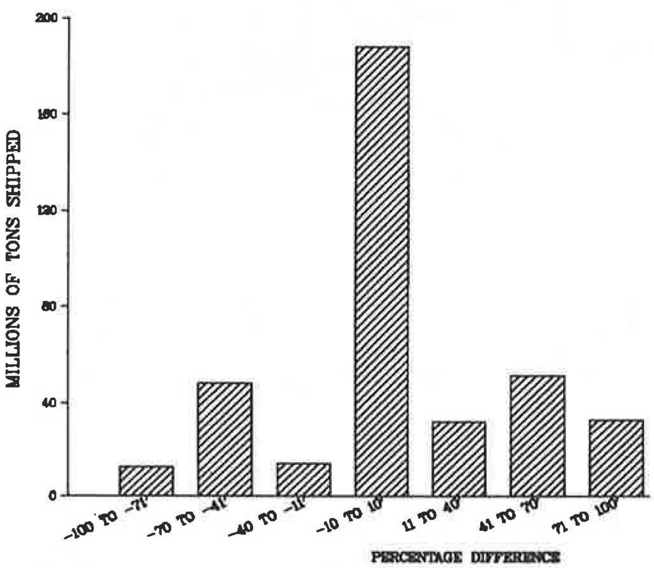
Total System

An overall comparison between the TFM and actual summary data appears in Table 1. Although there appear to be some discrepancies between the actual and TFM data, these figures must be evaluated within the context of the scope of this project. CEXEC's purpose in performing this task was to simply update the TFM's input files to the 1976 scenario and then evaluate the 1976 model runs for their utility in analyzing the U.S. coal transportation system. Also, the scope of the model does not include intrastate shipments included in the actual statistics provided by TAA. The summary statistics demonstrate the TFM's success in capturing the four-year trends in the rail and water network. Generally, ton splits are estimated best, ton-mile splits are best reflected for water shipments.

Table 1. Comparison of 1976 actual to 1976 model estimates (1922=100).

Factor	Actual	Model	Difference (%)
Rail			
Tons	96.5	98.4	2.0
Ton miles	102.0	93.5	-8.3
T$	137.8	150.7	9.4
M.Us/ton mile	135.3	161.1	19.1
$/t	142.8	152.9	7.1
Avg distribution	105.8	95.0	-10.2
Percentage rail (t)	98.3	96.7	-1.6
Percentage rail (t-miles)	98.4	97.9	-0.5
Water			
Tons	103.3	114.4	10.7
Ton miles	110.7	103.7	-6.3
T$	154.3	156.0	1.1
M.Us/ton mile	139.0	150.0	7.9
$/t	148.7	136.2	-8.4
Avg distribution	107.1	90.4	-15.6
Percentage water (t)	100.8	112.4	11.5
Percentage water (t-miles)	107.0	108.4	1.3

Figure 1. TFM versus actual rail coal tonnage.



Coal

The principal problem with the 1976 TFM run, with respect to coal transportation, is the grossly underpredicted average haul of water shipments. This occurs primarily because of the required model modification to use states as the regions of origin and destination for coal shipments. For neighboring states, separated by a navigable waterway, the TFM would route coal through adjacent ports, even though the coal may, in reality, be shipped between more distant ports. This problem caused by the use of states as the regional unit for coal shipments relates to the TFM's mechanism for carrier choice and calculation of transportation cost.

Carrier Selection

A comparison of the TFM's choice of interstate coal carriers with those listed in the baseline data indicated that the model closely duplicated the "actual" shipping mode selection process for all annual interstate coal shipments of more than 50 kilotons (Figure 1). Including smaller flows, the TFM's choice of carrier agreed with the actual data for 71.6 percent of the total coal tonnage shipped. The TFM appears to favor rail transportation as 17.6 percent was erroneously allocated to the railroads, while incorrect use of water carriers occurred for 10.9 percent.

Some discrepancies between the TFM results and the baseline data may be introduced by inherent comparability problems. The regional composition of the TFM is limited by the regional unit for coal shipments in the baseline data (states) and the exclusion of the Great Lakes shipping routes from the model's waterway network.

The use of states by the TFM as the points of origin and destination for coal shipments allows the model to select routes and carriers that were unavailable for use in the real world. Since the model enters and exits the transportation network from anywhere within the origin and destination states, it is likely that a shipment from Illinois to Indiana would be routed by the TFM from Cairo, Illinois, to Evansville, Indiana, by way of the Ohio River. This may be the least-cost route between these states, but it clearly would not facilitate accurate representation of an actual shipment that travels from Chicago to Indianapolis by rail. This situation would aid in explaining the misallocation of coal carriers between neighboring states where erroneous TFM route selections were most prevalent.

The exclusion of Great Lakes and Tidewater shipping routes from the TFM transportation network limits the TFM's ability to simulate actual flows. These routes accounted for 8.1 percent of the total 1976 coal movements. Shipments to and from the Great Lakes states are particularly affected; Michigan received 40 percent of its coal via the Great Lakes.

Another major consideration in evaluating the TFM's performance relates to the validity of the DOE baseline data. This data base represents a combination of seven different data sets. Some of the data had to be derived by extrapolation of trends observed from the information that was available. This became a potential limitation with respect to states of origin as all coal shipments were reported by originating U.S. Bureau of Mines (BOM) district. In cases of multistate BOM districts (there are 10) and states split among BOM districts (there are seven), the origin state data were derived by a weighted extrapolation procedure. This is likely to have introduced small interstate movements into the baseline file that have no counterpart in reality. Finally, even if a shipment traveled only 5 percent of the way on a barge, it would be recorded in the data as a wter shipment.

Terminating and Originating Regions

The TFM's ability to predict carrier selection for coal shipments terminating in each state is depicted in Figure 2. The TFM overprediction of rail transportation to Great Lakes states is due to the exclusion of lakewise routes from the model's waterway network. Shipments that are properly included in the ODMAST76 files as waterborne commerce could not be simulated properly. It is interesting to note that overprediction of rail (underprediction of water transportation) occurred for most of the states on the Ohio River system. In contrast, underprediction of rail occurred principally for states serviced by the Mississippi, Tennessee, or Warrior Rivers. This strongly suggests that the use of a single multiplier to update the TFM's water cost functions does not adequately reflect the regional changes in waterborne costs.

Accuracy of the model's predictions for carrier choice by state of origin is examined in Figure 3. The TFM tended to overpredict rail transportation from coastal states and states located on the Ohio River, while underpredicting rail volume from several states bordering the Mississippi. This resembles the regional patterns for destination states in regard to river route use and also highlights the effect of TFM network exclusion of Atlantic intercoastal water routes, which could explain the underprediction of water for coastal states.

CONCLUSIONS

As a result of the research project, the applica-

Figure 2. TFM coal carrier selection to destination states.

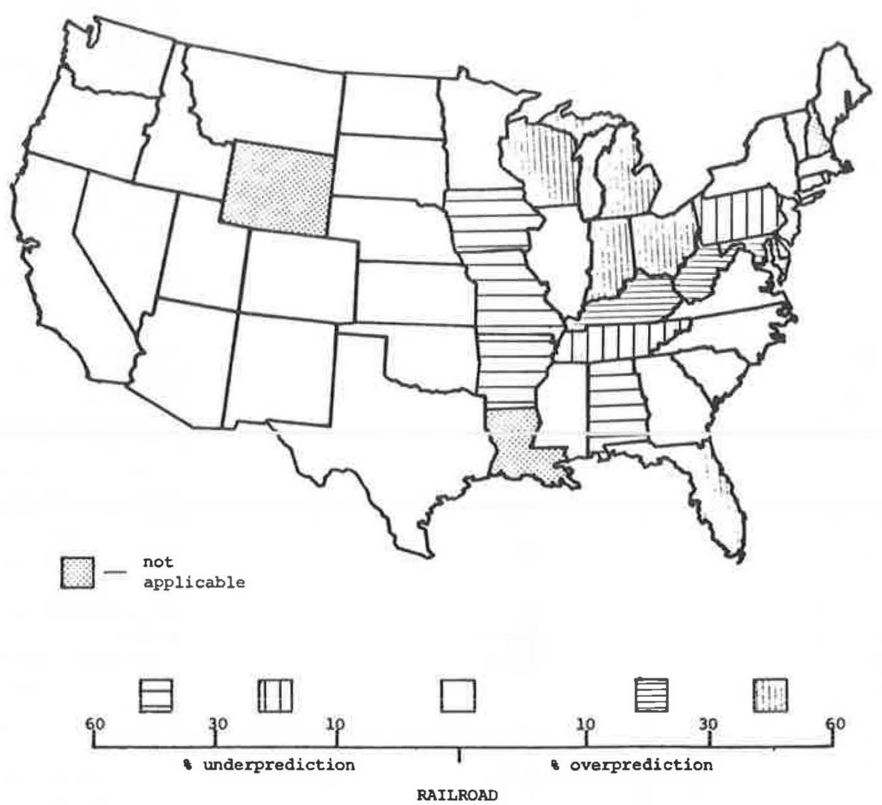


Figure 3. TFM coal carrier selection by state of origin.

bility for the TFM was accurately assessed. Generally, the data and model formulated logically represent the bulk freight network. Modal splits were, and rail costs are, verifiable in most cases. Water cost verification remains an open question.

Specific conclusions are as follows.

1. The model and data are internally consistent. Use of the specific values estimated for modal shares are reasonable in the majority of cases and track charges over time (midterm) well. Specific rail costs may be used if the results are tempered with analysis of rate issues. Best applications are likely to be found in scenario analyses.
2. The TFM should be sufficiently accurate to use as a tool in the wider analyses of commodity markets (e.g., the national coal market).
3. When sufficient baseline data exist for local areas, the TFM results provide a nationally consistent basis for providing control totals of traffic in, out (by direction), and internally.

To improve TFM performance, the following recommendations were made:

1. Coal origin and destination regions should be respecified as those of the Bureau of Economic Analysis.
2. Cost function data and logic should be enhanced to reflect class of service.
3. The TFM network should be extended to cover slurry pipeline and Great Lakes modes.
4. The cost functions should either be altered to reflect rates in the West, or results of the model should be analyzed in light of exogenous rate-cost differentials.
5. Detailed area models that use TFM results as input should be tested.

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Overview of Regional Fleeting and Intermodal Implications

W.G. TWYMAN

The importance of changing conditions related to fleeting in the area of the Port of Metropolitan St. Louis is discussed. The port occupies a unique position in the inland waterway system due to its strategic location. However, problems exist related to utilization of the riverbank area for industrial or commercial development and to the permit procedure of the U.S. Army Corps of Engineers, who are responsible for maintenance of most of the system. The fleeting operations in the port area are briefly discussed, and several possible future strategies are offered.

The Port of Metropolitan St. Louis occupies a unique position in the inland waterway system because of its strategic location immediately south of the confluence of the Missouri and Illinois Rivers with the Mississippi. All traffic then flows through the Chain of Rocks Canal, which enters St. Louis Harbor at mile 184. At that point the port becomes the equivalent of a railroad switchyard on the inland waterway system.

In addition, tows moving north to St. Louis can carry up to 40 barges per tow; but, moving from St. Louis north, they can only carry 15 barges per tow because of the configuration of the locks and dams to the north. There are no locks and dams on the Mississippi between St. Louis and New Orleans. Thus, a tow moving north to St. Louis can have barges in the tow destined for Chicago, St. Paul, and Omaha. On reaching St. Louis, they must be taken out of the tow and combined with tows going to those locations. Also, if the tow has 30 barges all destined for Chicago, for example, it must be broken up into two tows in order to proceed north. This operation is what is known as "fleeting" in the inland waterway system. St. Paul, Omaha, and Pittsburgh have this problem, as well as the Port of New Orleans, because they are the termini of the inland waterway system, and New Orleans could be involved in some fleeting moving along the intercoastal system to Houston or the Gulf.

About 82 percent of all movement on the waterside in the St. Louis port is this type of fleeting, for which the landside of the port receives practically no revenue. This is not true in the case of New Orleans, Pittsburgh, St. Paul, and Omaha. The barges that are fleeted in these areas are generally empty barges waiting to receive cargo that comes from the landside of the river and the surrounding area, or they are laden barges waiting to unload their cargo. Therefore, any product loaded in these barges generates economic value, both to the port and to the surrounding industrial or agricultural area. This is not the case in St. Louis, as these empty and loaded barges are purely a pass-through operation that generates practically no economic value to the port or the surrounding area.

In the entire metropolitan port, which consists of 70 miles on both sides of the river, we are fleeting between 750 and 1000 barges on any given day. Within an 18-mile area, with the north boundary being the MacArthur Bridge extending south below the Jefferson Barracks Bridge, there will be a total of 400 to 500 barges tied up to the riverbank on any given day. The MacArthur Bridge is at mile 179 and the Meramec to the south is at mile 161; therefore, fleeting can occur on 18 miles of river or 36 miles of riverbank as they now exist. There is some fleeting done farther south, but the area between the MacArthur Bridge and the Meramec River is the area primarily involved in fleeting. Of this 36 miles of riverbank, approximately 40 percent is not suited for fleeting because of sand bars and low water conditions and because of the proximity of the channel to the bank. Thus, about 22 miles of riverbank and water are usable for industrial development and fleeting in this area. By using 450 barges on any given day, six to eight miles of this riverbank are dedicated to fleeting. Thus, if 22 miles of riverbank are available for both fleeting and industrial development and 6 miles for fleeting, then the remaining 16 miles can be used for industrial development.

The activity on the waterside of the St. Louis port is dedicated to the maintenance of the inland waterway system rather than to the development of the port. If this were not a fleeting point, because of its strategic location, only some 25 barges per day would be needed for the maintenance of the industrial activity within the port. Unlike other ports where tows will sail past the port without touching land, St. Louis gets deeply involved in fleeting to support the operation of all other ports on the inland waterway system.

The A.P. Kearney Report (1), which was prepared for the East-West Gateway Coordinating Council and was based on growth studies; the Sverdrup and Parcel report; and the Booker Study (2), which was prepared for the Port Authority of the City of St. Louis forecast at least a doubling of the tonnage by the year 2000. If this takes place, and all indications are that it will, the fleeting problems will be very acute. In fact, unless something is done, it will be impossible to take care of the fleeting requirements of the inland waterway system in the metropolitan port.

ECONOMIC POSITION

From an economic standpoint all fleeting locations want to be as close to the entrance to the Chain of Rocks Canal as possible. Thus, as the year 2000 approaches, pressure is going to generate toward using what little industrial riverbank is available for the fleeting operation rather than for industrial development within the port.

Even today, the docks within the metropolitan port are at a disadvantage in getting loaded and empty barges delivered to their dock because of the need for the fleeters to handle the through tows rather than the delivery of loaded or empty barges to the various docks within the port. By far, the revenue to the fleeting companies is from the fleeting operation rather than from the delivery of loaded or empty barges to the docks within the port.

From an economic standpoint, the farther down river the fleeters are forced to go, the higher the cost of delivery of loaded and empty barges to the docks in the metropolitan port. The cost of transportation of through tows moving both north and south through the locks starting at Lock 27 will also be higher.

The Port of Metropolitan St. Louis is the largest port on the inland waterway system, yet the U.S. Army Corps of Engineers' responsibility for the maintenance of the Port of Metropolitan St. Louis is only to maintain a 300-ft channel, 9 ft deep at 3.5 ft on the gauge through this very large, busy port. As indicated earlier in this report, a good portion of usable riverfront is used for the maintenance of the inland waterway system rather than for industrial development within the port.

St. Louis Public Terminal is a case in point. This is a city-owned terminal leased to a private operator, but it cannot operate year-round because of a sand bar that forms immediately in front of the terminal. There have been seasons when the terminal has been out of business for periods of at least three months due to the inability to move barges into the terminal. The Corps dredges the channel, which lies on the east bank, continually to maintain the depth required by law and the dredge material is placed on the sand bar that is blocking the entrance to the St. Louis terminal. Thus, the problem is further complicated by the dredging activity. The public terminals immediately north and south of St. Louis terminals are faced with the same problem.

OTHER PROBLEMS

Other problems exist such as the permit procedure with the Corps of Engineers who must publish the request for a mooring permit for fleeting. This then involves both the state and the U.S. Environmental Protection Agency and the state's Departments of Fish and Wildlife, Natural Resources, and Conservation to register their objections, if they have any, to the issuing of a permit.

The 70 miles of port is not a fish and wildlife preserve such as would be found in a rural area, yet the same rules of disturbing fish and wildlife apply within the port district as apply outside the port district. By the time all of the hearings necessary are completed, almost two years elapse before a permit can be granted, both for fleeting and for the building of an industrial dock within the port. Many industrial companies are not willing to wait this long in order to get their project under way and will go where they have less difficulty in obtaining the proper permits.

It seems that a designated port district should come under different rules and regulations as far as fish, wildlife, natural resources, etc., are concerned. Only those areas that can, in fact, be considered as experiencing this type of problem should be considered under the standard rules and regulations laid down by the various agencies.

The same problem applies to the flood plain. The flood plain in a port for industrial development is being dealt with in the same manner as with flood plains and wetlands outside of the port. This approach creates restrictive problems in the development of unloading facilities.

One of the key bottlenecks in the Port of Metropolitan St. Louis is the fact that it is a major harbor; most of the riverfront is used to support the inland waterway system; and legislation designating the St. Louis port as a harbor has not been requested. The port authorities in the metropolitan port are going to have to seek legislation to have this declared a harbor. Funds must be appropriated to do the proper dredging to open up additional riverfront to meet the requirements of increased fleeting for the inland waterway systems, as well as to take care of industrial needs.

The study of the north riverfront, which starts at the Veterans Bridge and goes north to Maline Creek, shows that the St. Louis port has the potential of some 700 to 800 acres of land available for industrial development (2). Certain river problems have to be corrected prior to the development of this area.

FUTURE ACTIONS NEEDED

If the Port of Metropolitan St. Louis is to continue to support fleeting operations that are so essential to the maintenance and growth of water transportation, the Corps of Engineers is going to have to be authorized to make available riverbank and river water. These are necessary to the maintenance of the inland waterway system and for the development of water-related industry within the port.

If port authorities within the metropolitan port were not to renew the fleeting leases that they control within the harbor, it would force the fleeting operation to go south. This action would raise the cost of delivery of barges to the docks in the harbor, as well as raise the total operating cost of moving traffic within the inland waterway system. The ports themselves cannot afford to do the dredging necessary to support fleeting that generates little or no revenue for the port. Therefore, they have to look to the Corps of Engineers to be authorized to solve this problem.

It is the general consensus that the Port of Metropolitan St. Louis serves those adjacent municipalities bordering on the port. This is in part true. However, by far, a greater portion of the tonnage loaded and unloaded within the metropolitan port fans out to support industries and commerce within a 250-mile radius of the port itself.

Although the Port of Metropolitan St. Louis serves many industries within the United States, it is deeply involved in the export and import movement of goods. Because of the low cost of transportation by barge to the Gulf ports, grain producers in the United States can be more competitive in the foreign markets. A very high percentage of the grain movement from the Port of Metropolitan St. Louis is currently involved in foreign commerce to India, Pakistan, China, Poland, and many other countries that need agricultural products. In addition, walnut and oak logs are exported to Germany for the manufacture of veneer. By the same token, steel, fertilizer components, and casting to supply industry within the region are imported. The port is also in a position to be a very vital factor in the shipment of western coal and Missouri and Illinois coal to foreign markets.

In very few words, the port is vital.

REFERENCES

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Navigation on the Western Rivers

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The Second U.S. Coast Guard District is responsible for the safe navigation of ships that use the western river system of the United States. This paper briefly examines issues that bear directly on navigation safety, including aids to navigation, channel depths, and bridges.

The Second U.S. Coast Guard District, which has its headquarters in St. Louis, Missouri, has the responsibility for facilitating safe navigation of vessels on the western river system. This responsibility extends over an area ranging from Minneapolis-St. Paul and Chicago in the North to Baton Rouge in the South and from Pittsburgh in the East to Sioux City in the West. The Coast Guard derives its authority for that responsibility from numerous laws including Titles 10, 14, 33, and 46 of the U.S Code. These pertain primarily to its status as an armed service as well as to many regulatory functions and other responsibilities including search and rescue, aids to navigation, marine safety, bridge administration, and other law enforcement tasks. However, the comments here are limited to those matters that have a direct effect on the safety of navigation including aids to navigation, bridges, and channel depth.

The western river system is comprised of more than 6500 miles of navigable waterways that form a vast transportation-recreation system. This system, including the Arkansas, Cumberland, Illinois, Mississippi, Missouri, Ohio, Tennessee, and other rivers, extends into the industrial and agricultural heartland of the United States and makes Memphis, Vicksburg, Greenville, and New Orleans close neighbors of Chicago, Pittsburgh, Kansas City, and St. Louis. Although the system has been used for many years, it did not achieve its full potential until the U.S. Army Corps of Engineers developed its channels and constructed the many locks and dams. Today, that transportation network plays a vital role in the economy of the United States.

The Second Coast Guard District marks the channels of the system by using approximately 10 000 buoys and 3600 lighted and unlighted shore aids to navigation. (Incidentally, approximately 5500 of those buoys are lost each year as a result of high water, being run down by tows, etc.) In order to service those aids the Coast Guard operates a support base, five group offices, and 18 river buoy tenders. Continued efforts are made not only to improve maintenance of an adequate number of properly positioned buoys but also to develop improvements to the aids themselves. For example, recent improvements include the use of fast water buoys that will have less drag and improved buoyancy in swift water. Also, methods for enhancing visual detection of buoys have been developed. These include increased use of retroreflective materials and, most recently, the testing of a new "green paint". The new "green buoys" are being tested in St. Louis Harbor and near Cairo, Illinois. The Coast Guard conducted a special test of a radar transponder system that, it is hoped, will prove capable of identifying bridge piers on radar scopes. Obviously, this would be a valuable tool for assisting tows in making approaches on bridges during nighttime and other periods of reduced visibility. Testing of the transponder system took place recently on the Greenville Bridge.

The adequacy of aids to navigation from the perspective of the users, the towboat personnel in particular, is an important consideration. Thus, during the past year, the Coast Guard initiated a program for improving communications and working relationships between river interests in order to develop a viable feedback system. As a result, eight regional aids-to-navigation conferences that covered all major waterways were held in which towboat captains, river industry executives, Corps of Engineers' representatives, and Coast Guard buoy tender captains and staff members participated. It has been most rewarding to note that all individuals and organizations participating apparently benefited from these exchanges. Likewise, the Coast Guard has actively participated in development of the Master Plan for Management of the Upper Mississippi River and related studies such as the Great River Environmental Action Team (GREAT I, II, and III). Incidentally, recent studies have forecast a demand for transportation on the Upper Mississippi River that would result in a doubling of cargo tonnage by the year 2000. Thus, we must begin now to look at the impacts of increased traffic on the existing system and our responsibilities in providing a system that will accommodate that increase. Obviously, close coordination among federal agencies, the states, and the marine industry is vital if effective planning is to be achieved.

As a result of participation in preparation of the master plan and the GREAT studies, we have detected at least one trend that could result in a degradation in safety of navigation in the future. That trend applies to the amount of over-depth dredging or overdredging to be accomplished. To operate a 9-ft draft vessel, a depth greater than 9 ft is required. The Corps of Engineers has historically dredged to 13 ft; however, some environmentalists believe that it has no authority to dredge past 9 ft. For clarification, over-depth dredging is accomplished beyond the 9-ft depth and includes allowances for dredging tolerances, squat and trim for the class of vessels for which the project is currently used, wave action, shoaling rates, and other over-depth dredging. The objective of over-depth dredging is to reduce the need for frequent dredging while at the same time provide a safe and reliable channel.

Although the GREAT I study deals with the northern portion of the Upper Mississippi River, any action resulting therefrom could set a precedent for the other rivers. For that reason, certain aspects of the study are noted here for those who are primarily concerned with other waterways. A major product of the GREAT I study is a 50-year channel maintenance plan that provides for a reduced-depth-channel maintenance dredging program. A primary objective of that plan is to reduce the amount of material dredged by reducing the depth of the dredge cuts from the historic over-depth values to those no greater than necessary to ensure the integrity of a 9-ft channel for one navigation season. The track record thus far is less than impressive. The plan also recommends reduced channel widths in some areas. It appears that little or no consideration was given to the potential impact of that plan on navigation in terms of safety. The channel depth planned for the northern part of the Upper Mississippi River might not provide adequate under-keel clearance for currently used towboats and barges. Inadequate under-keel clearance will result in a degradation in controllability and an increased potential for groundings and collision. Whether or not the plan remains within acceptable levels has not been determined. For that reason the U.S. Department of Transportation could not approve the GREAT I study.

While dredging and channel maintenance are the primary responsibilities of the Corps of Engineers, the impacts that result from reduced channel depths are felt by all. Thus, it might be well to discuss some of them in more detail at this time. As noted previously, reduced depth dredging could seriously affect marine safety, a matter that is of considerable interest to the Coast Guard. Studies have shown that depths less than 1.5 times the vessel draft, or 13.5 ft in the case of typical 9-ft draft tows, have significant effects on a vessel's ability to maneuver or its controllability. Thus, the potential exists for increased collisions with other vessels as well as groundings. Other studies have documented the bottom suction effect in shallow water that can cause the lead barge in a tow to dive and ground, which results in a breakup of the tow. That effect is increased as under-keel clearances are diminished and is of particular notice when passing from deeper water to a shoal area. It should be realized that any increase in potential for collisions and groundings will be accompanied by a similar increase in the potential for spills of hazardous cargoes.

Although the Coast Guard is primarily interested in marine safety, the reader may be interested in two other factors that are basically economic in nature. First, fuel consumption is also affected by the depth of a channel. At a constant speed, a vessel's energy requirements will double when water depths are decreased from 18 ft to 13.5 ft. If the depth is decreased from 13.5 ft to 11 ft, there is another doubling of energy requirements, and likewise when the depth is reduced from 11 ft to 10 ft. The foregoing was determined from an examination of data obtained in a model test conducted at the University of Michigan Hydrodynamics Laboratory on an 8.5-ft draft tow (3 barges x 3 barges). Second, execution of the proposed channel maintenance plan noted earlier will require more frequent dredging than the present method. In other words, multiple shallow dredging cuts over a period of silting will be required to substitute for the present heavy-duty technique. In 1979 dredging costs increased six times over historical costs after being adjusted to account for inflation. If the GREAT I plan is approved, another substantial cost increase will result and additional dredging capability may be required. Incidentally, a shortfall in either funding and/or dredging capability will translate from an economic concern into one of navigation safety--inadequate under-keel clearance.

There are other constraints to navigation such as bridges and locks and dams. The Coast Guard is responsible for bridges insofar as they impact on navigation. Most of the bridges across the Mississippi River were either designed or built prior to 1900. The nature of marine traffic has changed dramatically since then, both in numbers and size of tows. Some of the bridges simply do not provide adequate clearance for safe passage of today's river traffic.

The GREAT II study identified 11 of 29 bridges in its area that have tow width to bridge opening ratios cited as producing higher accident rates. Bridge alignment relative to the channel and the width of span over navigable channels are also major factors in that regard. The correction of major bridge problem areas is a slow process as a result of both lengthy, but required, administrative procedures and limitations in funding. On the positive side, construction-corrective action is proceeding well on two bridges that present a serious hazard to navigation--the Hastings Bridge on the Upper Mississippi River and the Pearl Bridge on the Illinois.

The Corps of Engineers and the river industry have experienced considerable frustration in seeing that plans for elimination of river bottlenecks reach fruition. The Lock and Dam 26 project is a case in point. Predictions indicate that Lock and Dam 22 will reach capacity by the year 2000. It is hoped that action will be accelerated to permit timely execution of Corps of Engineers' plans in order that the river system will be ready to accommodate future needs. Similarly, early corrective action is deemed prudent at sites such as Gallipolis Lock and Dam, which presents an unusual, significant hazard to navigation on the Ohio River near Huntington, West Virginia.