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Transportation of Coal, Grain, and Passengers by Rail and Waterways

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Railroad Rate Deregulation: Effects on Corn and Soybean Shipments

JOHN J. MILLER, C. PHILLIP BAUMEL, AND THOMAS A. NARIGON

The effects of several possible rail-pricing strategies under rail deregulation on the degree of rail captivity of grain elevators and farmers in two areas in Iowa are examined. In phase 1 of the analysis, each elevator was assumed to have received the same amount of corn and soybeans that it did in the 1977-1978 marketing year. In phase 2, the corn and soybeans were assumed to be still on the producing farms, and farmers could shift to alternative markets in response to higher rates. In phase 1, simultaneous rail rate increases of 20-40 percent by all railroad companies above the rail rates in effect during most of the 1977-1978 crop year would have resulted in increased marketing costs to elevators of about 3.5-6.0 cents/bushel of corn and soybeans marketed in the Eastern District and about 7.5-14.5 cents/bushel in the Western District. Measured by the additional marketing costs that resulted from rail rate increases, railroads have more market power over elevators in the Western District than they do in the Eastern District, which is close to the Mississippi River. In phase 2, the same rail rate increases would have resulted in increased marketing costs of about 3.6-6.3 cents/bushel in the Eastern District and about 6.8-13.3 cents/bushel in the Western District, about the same per-bushel increase as in phase 1. However, in phase 2 the cost of hauling the corn and soybeans from farms to elevators was included. The market alternatives available for corn and soybeans located on farms are much greater than for that already delivered to elevators. The analysis showed that the principal beneficiaries of a rate increase by one railroad company would be the competing railroad companies and the elevators located on their tracks, whereas the railroad that raised its rate and the elevators located on its tracks would not benefit by this action.

The average return on investment in the railroad industry in 1978 was 1.6 percent; seven railroad companies lost money, and no major railroad had better than a 9 percent return on investment. During the past 15 years, the highest year for return on investment occurred in 1966, when the railroad industry earned an average of 3.9 percent. Since then, according to the Association of American Railroads' 1979 Yearbook of Railroad Facts, the trend in earnings has in general been declining.

The low earnings of the industry as a whole and the operating losses of several major railroad companies have resulted in continued deterioration of railroad plants and service. In the 1970s, several major railroad companies declared bankruptcy, and the Chicago, Rock Island and Pacific Railroad Company was ordered liquidated. Proposals to improve the earning performance of the railroad industry include restructuring the railroad industry by reducing the number of companies and miles of track, establishing balanced policies toward the competing modes, and reducing economic regulation of the railroad industry. A major element of reduced regulation would be greater rail-pricing freedom.

Many rail shippers have opposed giving the railroad industry additional rate freedom. Much of the resistance to increased rail rate freedom originates in the agriculture sector, particularly from shippers of grain and fertilizer. These shippers believe that they need rail rate protection in agricultural regions that have limited transportation alternatives. They believe that a reduction in regulatory protection as a result of increased rail rate freedom will establish the potential for excessive rail rate increases and discrimination among shippers.

The Staggers Rail Act of 1980 (Public Law 96-448) provides additional rail rate freedom over that permitted by the Railroad Revitalization and Regulatory Reform Act of 1976 (Public Law 94-210). The Staggers Act prohibits shippers from challenging rates on the grounds of reasonableness unless the rail rate exceeds a threshold ratio of revenue to variable cost of 160 percent in 1981 and rises to 180 percent after 1984. In addition, during the first four years after enactment, the act permits a railroad company to raise individual rates 6 percent/year above inflation-induced cost but not more than 18 percent total above inflation. Beginning after the fifth year, railroad companies without adequate revenues may raise rates 4 percent/year above inflation-induced costs.

The purpose of this analysis is to examine the effect of railroad rate increases on grain elevators, farmers, and carriers. The analysis does not attempt to determine whether railroad companies would find it beneficial to increase rates. Rather, the basic question asked in this analysis is, "What would happen to the costs of marketing and transporting corn and soybeans, to rail revenues, and to modal shares of corn and soybean shipments if rail rates are increased?"

The analysis is a case study of two areas in Iowa that produce corn and soybeans (1). One study area is located in eastern Iowa about 90 miles from the Mississippi River and is hereafter referred to as the Eastern District. The second study area is located in western Iowa about 225 miles from the Mississippi River and is hereafter referred to as the Western District. These study areas were selected in part to measure the effect of barge competition on railroad pricing options. Figures 1 and 2 show the railroad and highway networks in both study areas. An elevator is located in every town in both study areas.

Although many agricultural shippers assume that increased rail rate freedom will result in higher rail rates, one cannot know precisely what approach railroad companies will take in their new rate freedom. Therefore, the following rail-pricing strategies were analyzed to estimate their effects on the net cost of marketing and transporting corn and soybeans, on rail and truck revenues and ton miles, and on the share of corn and soybeans transported from the study areas by rail and truck:

1. Rail rates according to Interstate Commerce Commission Ex Parte 349 (Increased Freight Rates and Charges, 1978, Nationwide, May 21, 1981) during the 1977-1978 crop marketing year,
2. 20 percent increase in rail rates,
3. 30 percent increase in rail rates,
4. 40 percent increase in rail rates,
5. 20-cent/hundredweight increase in rail rates, and
6. In phase 2, increase in rail rates of 20 percent by one railroad independently.

METHOD OF ANALYSIS

A linear-programming model was used to evaluate the effect of these rail-pricing strategies on the flow of corn and soybeans to alternative markets and on farmers, elevators, railroads, and competing modes. A base solution was computed to optimize the flow of corn and soybeans by using 1977-1978 crop year supplies, Ex Parte 349 rail rates, estimated trucking

Figure 1. Eastern District study area.

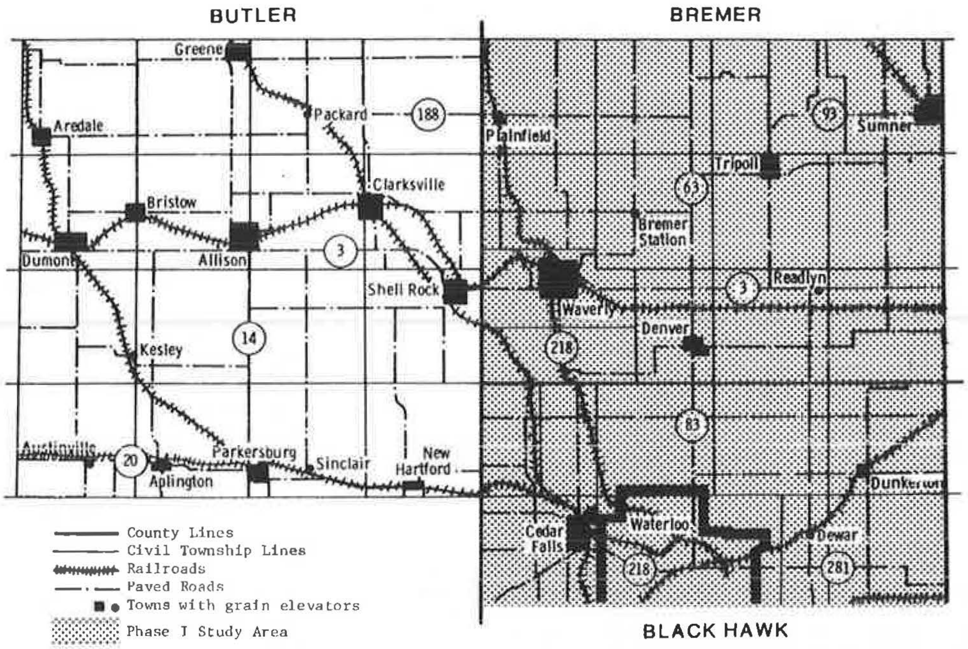
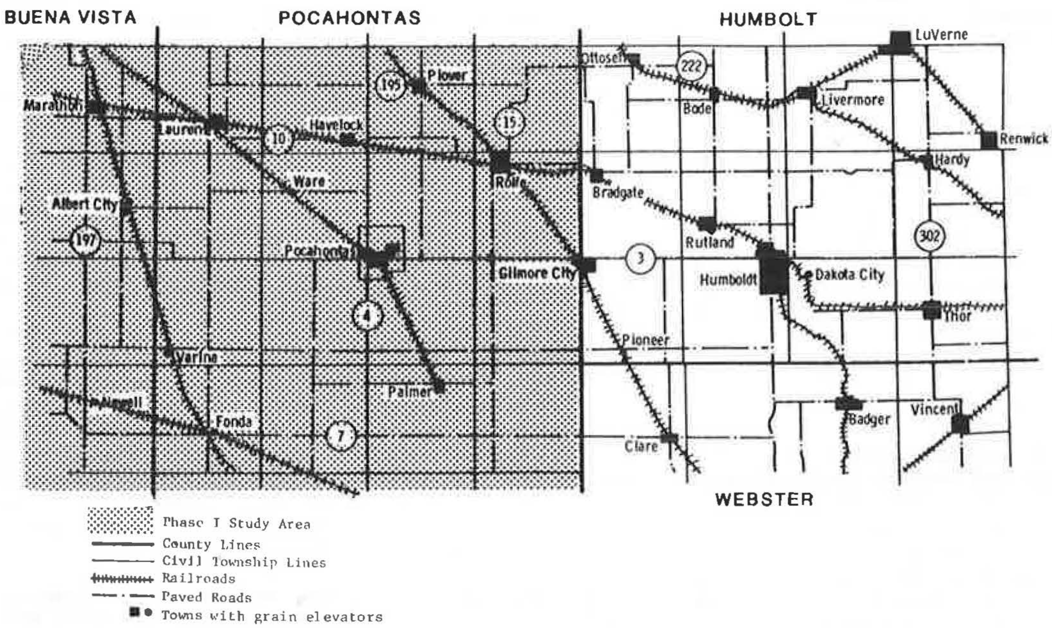


Figure 2. Western District study area.



costs, and prices paid at alternative markets during the 1977-1978 marketing year. Alternative solutions were computed in which rail rates were increased but all other variables remained constant. The effect of the higher rail rates on farmers, elevators, railroads, and competing modes was estimated by calculating the differences between the base solution and the alternative solutions that used higher rail rates. Differences between the base solution and each alternative solution that used higher rail rates were computed for total transportation and marketing costs, ton miles of corn and soybeans hauled by rail and truck, total transportation revenues earned by rail and truck, and total rail and truck ton miles of corn and soybeans shipped by various groups of elevators.

The analysis was divided into two phases. In phase 1, each elevator in each study area was assumed to have received the same volume of corn and soybeans as it did in the 1977-1978 marketing year, and it was assumed that the level of investment in elevator facilities was constant. In phase 2, the corn and soybeans marketed in the 1977-1978 marketing year were assumed to be located on farms so that farmers could shift corn and soybeans among elevators in response to changing rail rates. Also, elevators or farmers (or both) could invest in new grain-storage facilities. Farm origins were defined as areas 6 miles^2. The size of the study areas for the phase-2 analysis was increased to provide farmers a wider range of market options. Table 1 shows the number of elevators in each district and the total bushels of corn and soybeans received and shipped during the 1977-1978 marketing year. Data on elevator capacities, bushels received and shipped, and market destinations were obtained by personal interviews. Figures 3 and 4 show the 1977-1978 corn flow from elevators in the phase-2 analysis for each study district.

Phase-1 Objective Function

The general objective of each phase-1 computer solution was to maximize total net revenue to all elevators within each study area for the 1977-1978 crop year, given the prices paid for corn and soybeans at alternative markets, the transportation rates specified for each solution, and the constraints imposed on the model. Ex Parte 349 rail rates, effective during 1977-1978, were used in the base solution. Alternative solutions were based on rates higher than the Ex Parte 349 level. The differences in the estimated values of the base computer solution and each alternative computer solution represent the estimated effects of the higher rail rates on corn and soybean flows, marketing and transportation costs, modal shares and revenues, and on different groups of elevators.

Table 1. Elevators and corn and soybean shipments during the 1977-1978 marketing year.

Study Area	No. of Elevators	Corn and Soybean Receipts (bushels 000 000s)	Corn and Soybean Shipments (bushels 000 000s)
Eastern District			
Phase 1	16	18.1	17.9
Phase 2	32	33.1	29.9
Western District			
Phase 1	13	31.3	30.3
Phase 2	28	57.7	56.5

Figure 3. Corn flow from Eastern District in 1977-1978 marketing year from elevators in phase 2.

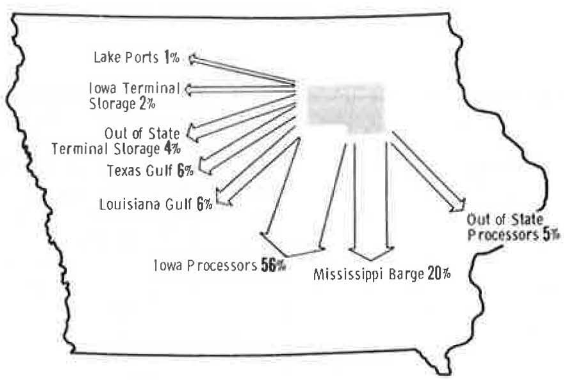
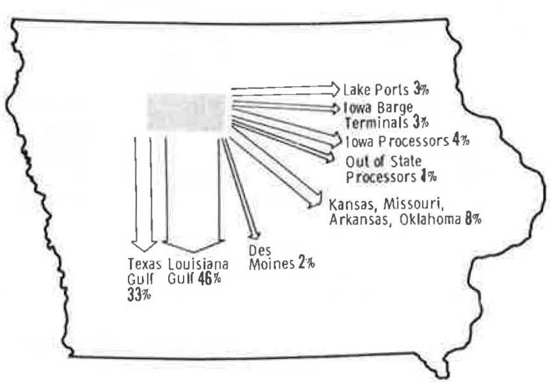


Figure 4. Corn flow from Western District in 1977-1978 marketing year from elevators in phase 2.



Phase-2 Objective Function

The objective of each phase-2 computer solution was to maximize total net revenue to all elevators and farmers within each study area for the 1977-1978 crop year, given the prices paid for corn and soybeans at alternative markets, the transportation rates specified for each solution, and the constraints imposed on the model. The constraints placed on the phase-2 model were identical to those placed on the phase-1 model except that elevator and farm storage capacities were allowed to increase in the phase-2 model.

Prices paid for corn and soybeans at final destinations are a major variable that affects grain flows. Higher rail rates may force a shipper to shift to a market that offers a lower price. The price effect from shifting to alternative markets was incorporated into the model in this analysis. Thus, the additional marketing and transportation costs that result from the higher rail rates include the price effects of shifting to alternative markets, additional handling and storage costs, and additional transportation costs.

The grain industry typically quotes the "basis" rather than the absolute level of grain prices to reflect demands at alternative markets. In this analysis, "basis" is defined as the difference in cents per bushel between the local cash price for grain and the nearby futures contract for the same grain on the Chicago Board of Trade. The basis can be divided into three components: (a) handling and storage costs to the future delivery month, (b) transportation cost to a market destination, and (c) difference between the cash price at the market destination and the nearby Chicago futures price. Therefore, a basis varies by time and by location.

The grain industry prefers to price grain in terms of the basis because the level of futures and cash prices can fluctuate widely from day to day. Although there are some seasonal tendencies in grain prices, the ability to forecast the future price of a grain is more of an art than a science. However, the difference between the futures price and the cash price (i.e., the basis) is much more stable and tends to follow a similar pattern from year to year. The basis tends to decrease or narrow by the amount of reduced storage costs as the delivery month is approached. Because of its stability relative to the actual level of daily cash and futures prices and the predictability of its seasonal movements, the basis is the preferred method of pricing grain. Although the basis is more stable than absolute prices, a local basis may change from time to time for any number of reasons. An increase or widening of the local basis and the concomitant relative decline in the local price could occur because of an increase in transportation costs, a shortage of railroad cars, a shortage of storage capacity, or a lowered demand for grain. A narrowing of the basis and the corresponding relative increase in the local price could occur because of a decrease in transportation costs, a strong demand for grain, or a local shortage of grain.

The linear-programming model was constructed so that it minimized total transportation, handling, and storage costs net of basis improvement over the crop year. By substituting the basis for the prices paid for corn and soybeans at destination markets, minimizing the objective function is equivalent to maximizing total net revenue to all elevators. Proof of this equivalence can be made by defining the basis at a final destination as in Equation 1, the basis at an elevator as in Equation 2, and the maximum net price to an elevator in a time period as in Equation 3:

$$B_{jkt} = FP_{kt} - CP_{jkt} \tag{1}$$

where

B_{jkt} = basis at destination j for commodity k in time t,
FP_{kt} = Chicago futures price of designated futures contract for commodity k in time t, and
CP_{jkt} = cash price at destination j for commodity k in time t.

$$B_{hkt} = FP_{kt} - NP_{hkt} \tag{2}$$

where

B_{hkt} = basis at elevator h for commodity k in time t, and
NP_{hkt} = maximum net price at elevator h for commodity k in time t.

$$NP_{hkt} = \max_{j} (CP_{jkt} - T_{hjkt} - H_{hk}) \tag{3}$$

where

T_{hjkt} = per-bushel transportation cost from elevator h to destination j for commodity k in time t, and
H_{hk} = handling and storage costs at elevator h for commodity k.

By substituting the equivalent of CP_{jkt} from Equation 1 and NP_{hkt} from Equation 2 into Equation 3, Equations 4 and 5 can be derived as follows:

$$FP_{kt} - B_{hkt} = \max_{j} (FP_{kt} - B_{jkt} - T_{hjkt} - H_{hk}) \tag{4}$$

$$B_{hkt} = \min_{j} (B_{jkt} + T_{hjkt} + H_{hk}) \tag{5}$$

The sequence of definitions and substitutions illustrates that maximizing the net price at an elevator is equivalent to minimizing the basis at an elevator. The minimum basis at an elevator can be obtained by minimizing over all final destinations the sum of the basis at a destination plus the transportation and handling costs to that destination. An increasing number of farmers are using the basis to decide where and when to sell their crops. Thus, the minimization objective function applies to both elevators and farmers.

Country elevators that sell corn and soybeans to final markets face negatively sloping demand functions. Other things being equal, as the quantity of corn and soybeans offered to each market increases, the price paid at the market decreases, which makes bids at other markets better alternatives. Unfortunately, accurate estimates of demand functions at each final market do not exist. The corn and soybean prices used in the model are average quarterly bids at each final market. To prevent the quantity of corn and soybeans shipped to each market from exceeding the quantity that each market can receive without significantly affecting its bid price, the quantity of corn and soybeans that can be shipped to each market was constrained in the model.

Corn and soybean markets historically served by the elevators within a study area are divided into three major categories: inland terminal storage markets, processing markets, and export markets. Corn and soybean receipts at processing markets are constrained in the aggregate to be between 90 and 110 percent of their 1977-1978 quarterly levels. Export markets are constrained identically. Receipts at individual corn or soybean processors, Great Lakes export markets, and inland terminal storage markets are constrained to be equal to or less than 110 percent of their 1977-1978 quarterly levels. Barge shipments of corn and soybeans from each study area to barge-loading elevators are constrained to be between 80 and 130 percent of their 1977-1978 quarterly shipments.

In the phase-1 analysis, the storage capacity, beginning crop-year stocks, quarterly receipts, and ending crop-year stocks of corn and soybeans at each elevator are fixed at their 1977-1978 levels. In the phase-2 analysis, the total 1977-1978 supply of corn and soybeans on each farm must be shipped to an elevator or stored in on-farm storage facilities in the first time period--harvest 1977. The phase-2 analysis permits additional on-farm and elevator storage facilities to be built to accommodate any expansion in the 1977 storage capacity of on-farm and elevator storage facilities demanded. Thus, farmers could shift corn and soybean shipments among elevators and time periods in response to changing rail rates. Additional on-farm and elevator storage costs were converted to an annual fixed investment cost by using Equation 6 (2):

$$AFIC = P\left\{i(1+i)^n[(1-i)^n - 1]^{-1}\right\} - S\left\{i[(1+i)^n - 1]^{-1}\right\} \tag{6}$$

where

AFIC = annual fixed investment cost,
P = purchase price,
S = salvage value,
n = service life, and
i = interest rate.

RESULTS

Table 2 shows the values of the objective function for each solution in the phase-1 analysis. Simultaneous rail rate increases of 20-40 percent by all railroad companies above the Ex Parte 349 rail rates in effect during most of the 1977-1978 crop year would have resulted in increased marketing costs for elevator operators of about 3.5-6.0 cents/bushel of corn and soybeans marketed in the Eastern District. The same level of rail rate increases in the Western District would have resulted in increased marketing costs of about 7.5-14.5 cents/bushel of corn and soybeans. The additional marketing costs incurred by elevator operators in the Western District would have been about twice as large as those incurred by elevator operators in the Eastern District. Measured by the additional marketing costs that result from rail rate increases, railroad companies have more market power over elevator operators in the Western District than they do in the Eastern District. A major reason for the differences in market power is the distance to the Mississippi River. An analysis of the effects of the higher rail rates on different groups of elevators indicates that the elevators most likely to absorb large increases in rail rates before shifting to another mode of transportation or to another market or both were elevators that

1. Ship multiple-car or unit grain trains,
2. Ship more than 70 percent of their corn and soybeans by rail,
3. Ship corn and soybeans more than 300 miles to market, or

4. Ship under relatively low-cost rail rates and have ratios of revenue to variable cost of less than 1.6.

Rail rate increases of 20 cents/hundredweight would result in hauling less corn and soybeans by rail and more by truck. The 20-cent/hundredweight increases would result in doubling the rail rates for some short-distance movements and would cause increases of a much smaller percentage in rates for longer distances. Thus, long-distance shippers were more likely to absorb large increases in rail rates than were short-distance shippers.

The elasticity of demand for rail transport of corn and soybeans was calculated by using the percentage of rate increases and the ton miles of corn and soybeans shipped by rail. The elasticity of demand is defined as the ratio of the percentage of change in quantity transported by rail divided by the percentage of change in rail rates. In the Eastern District's solution of a 20 percent rail rate increase, the quantity of rail ton miles declined by 21.6 percent. Thus, the estimated elasticity of demand for rail services in the Eastern District is 1.07; this is an elastic demand at the Ex Parte 349 rail rate level with the 20 percent rate increase. In the Western District, the elasticity of demand was estimated to be 0.05 at the 20 percent rate increase. This is highly inelastic.

Table 3 shows the values of the objective function for each solution in the phase-2 analysis. On the basis of the results of the phase-2 analysis--when corn and soybeans were assumed to originate on the farm--rail rate increases of 20-40 percent would result in increased marketing costs of about 3.6-6.3 cents/bushel of corn and soybeans marketed in the Eastern District. This was about the same per-bushel price increase as in the phase-1 analysis. However, the phase-2 analysis included the cost of hauling the corn and soybeans from farms to elevators, whereas the phase-1 analysis excluded the farm-to-elevator transportation costs. In addition, the center of the Eastern District in the phase-2 analysis is located somewhat further from the Mississippi River than the center of the phase-1 Eastern District. If the phase-2 Eastern District had been exactly the same geographic size and had had the same mix of elevator types as the phase-1 Eastern District and if the farm-to-elevator transportation costs had been included in the phase-1 analysis, logic would have led to the conclusion that railroads have less market power over farmers than over elevators. The marketing alternatives for corn and soybeans still on farms are much greater than for corn and soybeans already delivered to elevators.

Similar results were obtained in the Western District. The additional marketing costs in the Western District were about 6.8-13.3 cents/bushel under the phase-2 analysis compared with 7.4-14.5 cents/bushel in additional costs in the phase-1 analysis. Thus, the per-bushel increase in marketing and transportation costs was about the same in phases 1 and 2 of the analysis. The phase-1 analysis, however, did not include the farm-to-elevator transportation costs. There is little difference in the mix of elevators among the elevators in phases 1 and 2 in the Western District. If the phase-2 study area had been the same geographic size as the phase-

Table 2. Estimated value of objective function for five computer solutions, Eastern and Western Districts, phase 1.

	Eastern District			Western District		
		Change in Net Price, Transportation, and Handling Costs Due to Rail Rate Increases			Change in Net Price, Transportation, and Handling Costs Due to Rail Rate Increases	
Solution	Total Transport and Marketing Costs and Futures Basis ($)	Dollars	Cents per Bushel	Total Transport and Marketing Costs and Futures Basis ($)	Dollars	Cents per Bushel
Base	8 209 456			12 491 745		
Rate increase of						
20 percent	8 838 696	629 240	3.51	14 684 777	2 193 032	7.4
30 percent	9 078 682	869 226	4.85	15 768 539	3 276 794	11.0
40 percent	9 276 095	1 066 639	5.95	16 825 018	4 333 273	14.5
20 cents/hundredweight	9 183 018	973 562	5.43	15 613 208	3 121 463	10.5

Table 3. Estimated value of objective function for six computer solutions, Eastern and Western Districts, phase 2.

	Eastern District			Western District		
		Change in Net Price, Transportation, Handling, and Facility Costs Due to Rail Rate Increases			Change in Net Price, Transportation, Handling, and Facility Costs Due to Rail Rate Increases	
Solution	Total Transport and Marketing Costs and Futures Basis ($)	Dollars	Cents per Bushel	Total Transport and Marketing Costs and Futures Basis ($)	Dollars	Cents per Bushel
Base	19 006 253			33 467 784		
Rate increase of						
20 percent	20 108 584	1 102 331	3.64	37 305 603	3 837 819	6.79
30 percent	20 542 044	1 535 791	5.07	39 168 067	5 700 283	10.09
40 percent	20 876 703	1 870 450	6.18	40 998 909	7 531 125	13.33
20 cents/hundredweight	20 905 004	1 898 751	6.27	39 151 413	5 683 629	10.06
One railroad only, 20 percent rate increase	19 218 018	211 765	0.70	34 588 619	1 120 835	1.98

1 study area and if farm-to-market transportation costs had been included in the phase-1 analysis, logic would have led to the conclusion that railroads have less market power over farmers than over elevators. This is because farmers must incur the fixed costs of transporting their grain regardless of where they sell it. Therefore, farmers only incur the marginal costs of transporting their grain to more-distant elevators or markets in response to higher rail rates. Elevators, on the other hand, incur the full cost of trucking their grain to other markets plus the costs of handling the grain the second time. The phase-2 results also suggest that railroad companies have more market power in areas farther from the Mississippi River than in areas closer to it.

The analysis of the effects of the higher rail rates on different groups of elevators and farmers indicates that the elevators and farmers most likely to absorb large increases in rail rates before shifting to another mode of transportation or to another market are those that

1. Ship multiple-car or unit grain trains,
2. Ship more than 70 percent of their corn and soybeans by rail,
3. Ship corn and soybeans more than 300 miles to market, or
4. Ship under relatively low-cost rail rates and have ratios of revenue to variable cost less than 1.6.

Typically, elevators that ship multiple-car or unit trains of corn and soybeans have lower rail rates to distant export ports than do elevators that ship smaller units. The percentage of rate increases applied to these lower rates results in smaller absolute rate increases than when it is applied to higher-cost small shipments. Moreover, most of the rail rates that have ratios of revenue to variable cost less than 1.6 were for multiple-car or unit-train shipments to export ports. Also, elevators that ship by low-cost multiple-car and unit trains of corn and soybeans ship most of their grain by rail. As a result, only farmers who sell to and elevators that ship corn and soybeans in multiple-car and unit trains shared all four of the preceding characteristics.

By using rail ton miles as a measure of quantity, the estimated elasticities of demand for rail transport under the phase-2 20 percent rate-increase solutions are 1.06 in the Eastern District and 0.19 in the Western District. Thus, the elasticity of demand for rail transport is less inelastic in the Western District when the corn and soybeans are still on the farm than when they have been delivered to elevators.

In the phase-2 analysis, rates of one railroad company were increased 20 percent over the base solution rates, whereas all other rates were held constant. In that computer solution, the rates of the Chicago and North Western Transportation Company (C&NW) were raised because about 50 percent of the elevators in both districts are located on C&NW tracks. When only one company's rates were raised 20 percent, total corn and soybean marketing costs would have increased only 0.7 cent/bushel in the Eastern District (compared with 3.6 cents/bushel when all railroad companies raised their rates) and slightly less than 2 cents/bushel in the Western District (compared with 6.8 cents/bushel when all railroad companies raised their rates). The reason for the small increases in marketing and transportation costs is that farmers would have bypassed elevators located on C&NW tracks. Table 4 shows the impact of the higher rail rates on C&NW rail revenues and ton miles as well as revenues and ton miles for competing companies that did not raise their rates. C&NW rail revenues and ton miles would have declined more than 80 percent in both districts, whereas rail revenues and ton miles for competing companies would have increased 36 and 70 percent, respectively, in the Eastern District and 130 and 140 percent, respectively, in the Western District. Elevators located on competing railroad company tracks would have received and shipped about 17 percent more corn and soybeans in the Eastern District and 105 percent more corn and soybeans in the Western District. Thus, the principal beneficiaries of a one-railroad rate increase would be the competing railroad companies and the elevators located on the competing railroads' tracks. Farmers who sold their grain to elevators on C&NW tracks in the base solution would minimize the effects of the one-railroad increase in rates by shifting their grain sales to elevators located on competing companies' tracks. The principal losers would be the railroad that raised its rates and the elevators located on its tracks.

If we assume that railroad companies possess market power in various degrees and locations, it is not certain that they will fully exercise rate freedom under a deregulation scenario. If the corn and soybeans have been delivered to elevators, a 20 percent rail rate increase by all railroad companies operating in the Eastern District would reduce total railroad revenues from corn and soybeans about 13 percent, whereas rail ton miles would decline about 21 percent. If the corn and soybeans were still located on farms, a 20 percent rail rate increase by all railroad companies would reduce rail revenues about 18 percent and rail ton miles about 21 percent in the Eastern District. It is not possible to determine railroad profitability from gross revenues

Table 4. Impact of higher rail rates on number of shipments, rail revenues, and ton miles for C&NW and competing companies.

Item	Base Solution		One Railroad and 20 Percent Rate Increase			
	C&NW Elevators	All Other Elevators	C&NW Elevators	Percentage of Change from Base Solution	All Other Elevators	Percentage of Change from Base Solution
Eastern District						
Total corn and soybean shipments by rail and truck (bushels)	11 116 800	19 098 200	7 985 600	-28.5	22 279 400	16.7
Total rail revenue paid ($)	2 638 485	4 102 604	504 667	-80.9	5 592 184	36.3
Rail ton miles (000s)	137 928	134 248	22 893	-83.4	228 421	70.1
Western District						
Total corn and soybean shipments by rail and truck (bushels)	35 322 800	21 179 800	13 079 800	-63.0	43 422 800	105.0
Total rail revenue paid ($)	11 950 749	7 760 276	2 255 770	-81.1	17 839 245	129.9
Rail ton miles (000s)	990 573	596 608	143 329	-85.5	1 428 280	139.4

and ton miles. But, since both rail revenues and ton miles would decline by approximately the same amount and given the high fixed costs of the railroad industry, it is likely that there would be less revenue to cover the fixed costs. In this case, rail profits would likely decline. In the short run, it may be possible to raise rates 20 percent in the winter when the Mississippi River is frozen and still maintain total corn and soybean rail shipments and increase rail profits. In the long run, however, higher winter rates would encourage elevator operators and farmers to sell more grain at harvest or build more storage or both so that corn and soybean sales could be shifted to spring and summer shipments. If one railroad company raised its rates independently in the Eastern District, enough corn and soybean revenue and ton miles would be lost to result in lower rail earnings.

In the Western District, the probability is higher that railroad companies would more fully exercise their rail-rate freedom. Rail rate increases would result in substantially higher rail revenues, whereas ton miles would decline slightly. This would increase rail profits sharply. However, if one railroad company independently raises its rail rates while all other rail rates and variables remain constant, the company that raised its rates would lose more than 80 percent of its gross revenues and rail ton miles of corn and soybean shipments. Thus, it would seem to be unprofitable for one railroad company to raise its rates independently. This conclusion must be tempered somewhat, because some of the rail competition that existed in both study areas in 1977-1978 no longer exists. The Chicago, Rock Island and Pacific Railroad Company has ceased operation in both areas since the analysis. One method of preventing railroad-company abuse of market power under deregulation is to remove antitrust exemption from railroad rate bureaus, which would prevent railroad companies from simultaneous rate-making activities. Railroad companies would be required to publish rates only on independent action. Joint rates on end-to-end line-haul movements would need to be negotiated on a one-to-one basis. In a deregulated environment, however, railroad rate bureaus could still have the function of mechanically printing and distributing railroad price lists. The Staggers Rail Act of 1980 prevents rate-bureau discussion or voting on single-line rates except for general rate increases and precludes the latter after 1983.

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Fuel Efficiency in Freight Transportation

SAMUEL EWER EASTMAN

Barge transportation is the most fuel-efficient method of moving the raw materials and semifinished products needed by the nation's economy. This study reviews the record of extensive research on this vital issue and provides findings that lend new perspective to energy efficiency in transportation. A number of studies of fuel efficiency have been sponsored over the past several years by the U.S. Departments of Transportation and of Energy. These studies show that shallow-draft water transportation consumes considerably less energy in producing equivalent freight transportation than do alternative modes. Even when circuity (the lack of straight-line water routes between cities) is taken into account, the energy efficiency of the barge and towing industry is superior. These analytical findings are confirmed by a survey of barge operators and reinforced by specific examples—grain movements from Minneapolis to the Gulf Coast and a total of 25 million tons in coal movements to steam-generating plants of the Tennessee Valley Authority. All bulk-transport modes make significant contributions to the nation's distribution system in a highly fuel-efficient manner. Any transportation energy policy must recognize and promote the use of the inherent advantages of all the fuel-efficient modes of transportation.

Nearly 25 percent of domestic freight traffic and more than 16 percent of all intercity freight moves by water (1, p. 8; 2, p. 91). An analysis of published studies, carrier filings with the Interstate Commerce Commission (ICC), and data from railroad and waterway companies shows that, on the average, after both rail and water circuity have been taken into account, domestic water carriers consume less energy in producing equivalent work than does the rail mode. In this analysis, the facts on fuel efficiency in freight transportation are reviewed. Particular attention is paid to the rail and water modes.

A wealth of data on efficiency in the use of energy has been developed in recent years, mostly under contracts for the U.S. Department of Energy (DOE) and the U.S. Department of Transportation (DOT) (3, p. 9). Rising cost of fuel, occasional uncertainties of supply, and possibility of catastrophic interruption of fuel supplies from the Middle East have concentrated the attention of transportation companies on improved efficiency.

One major conclusion of a review of the available information is that the vital task of distributing the production of industry and agriculture (thus keeping farms and factories running) is accomplished by using a fraction of the nation's total fuel supplies. It is well understood that more than half the nation's petroleum is consumed by transportation. It is not so well understood that most of this goes for passenger transportation.

Trucks, railroads, and water carriers perform more than 76 percent of intercity freight transportation, but in 1978 they consumed less than 6 percent of the nation's total domestic demand for petroleum (excluding residual fuel oil used mainly in bunkering vessels engaged in foreign trade) (4, p. I-5) and less than 3 percent of the nation's fuel supply. Barging alone consumed about one-half of 1 percent of the nation's fuel supply (5, p. 2-8; 6, p. 32). Petroleum demand for trucks is estimated based on 602 trillion ton miles at 2.343 Btu/ton mile. The Transportation Association of America's value for diesel fuel and distillate is taken as the water and barge petroleum energy demand. Rail passenger demand was taken to be 5.6 x 10^6 bbl (5, p. 2-13). These facts reinforce the wisdom of policies that assure 100 percent of the fuel requirements for the freight transportation modes in the event that fuel allocation becomes a necessity, so that disruption in the distribution of the products of farms and factories will be minimized.

In an extreme emergency, it is possible to conceive that fuel efficiency will become an important criterion for allocating the work of transporting freight. Some truck traffic could be diverted to rail and some rail traffic diverted to water. Measures that had a similar effect were introduced during World War II to conserve fuel and rubber (7).

COMPARISON OF TON-MILE PRODUCTION AND ENERGY CONSUMPTION

Special studies of relative energy efficiency--or energy intensity as it is often called--were conducted for DOE and DOT in the 1970s (3). These studies use the number of British thermal units consumed in the production of a net ton mile of transportation services as a measure of energy efficiency. This provides a common standard for gasoline, diesel, and residual fuel oil. For example, 1 gal of number 2 diesel fuel yields 138 700 Btu (5).

Most of the government studies are quite detailed and are built around models from which conclusions are calculated. These conclusions have been confirmed from independent data filed with the ICC or from company reports. For example, one study of railroads uses equations that report rolling resistance plus aerodynamic drag plus resistance on curves and grades plus assumptions on percentage of fuel lost or spilled, percentage spent in idling, and, finally, percentage spent on switching and assembling trains. The conclusion is an estimate of 670 Btu/ton mile as an average for rail (8, pp. 5-1, S-9). This is further confirmed by dividing out the reported ton miles of 12 railroads and their total fuel consumed as recorded by the ICC. The resulting figure is 644 Btu/ton mile, which is close to the aggregate or average value based on the analytical model (data are for 1976) (9, p. 220).

A further confirmation comes from the most recent DOT study of the different modes and may be used to illustrate the arithmetic. Dividing fuel consumed (in trillions of Btu) by ton miles [Table 1 (10, pp. 31, 33, and 34)] shows that rail consumes 686 Btu/ton mile compared with 270 Btu/ton mile for barge. This would suggest that for total work performed, barge is two and a half times more energy efficient than rail in a comparison of route miles of service.

A method frequently used by the railroad industry for comparing fuel efficiency of the several modes is to calculate the miles that 1 ton of freight can be carried per gallon of fuel. Figure 1 (which is based on the data in Table 1) shows this relationship and adds the barge dimensions as well.

UPDATING RAIL AND BARGE DATA

As shown in Table 2, the values from several different studies that give an average energy intensity for railroads vary within a narrow range. Those for the water carriers, also shown in Table 2, have a somewhat greater spread, due in part to different technologies employed in inland, Great Lakes, and coastwise water transportation. For both modes the values from the different studies and answers to surveys are remarkably consistent. There have been some incorrect characterizations of water transport and misuse of data in articles and advertisements. For example, an article by D.S. Paxson (13) based on a study by the U.S. Department of Commerce (14) reports the value of 495 Btu/ton mile for barge compared with 396 Btu/ton mile for unit train. The following comments may be made:

1. The article compares "best" (unit train) by rail with "average" for water; "best" by barge would be 103 Btu/ton mile downstream on the Mississippi River (12, Tables II.9 and II.10, pp. II.28 and II.29);
2. A later study by F.H. Leilich reports 272 Btu/ton mile for "average" barge (12); and
3. The value for barge in the U.S. Department of Commerce study (14) seems high; this is explained by the study definition of "water" to include "domestic deep sea".

The Southern Railway System, in advertisements in various publications for 1979-1980, reported values of 670 Btu/ton mile for railroads versus 680 Btu/ton mile for waterways. [Southern Railways gives a study by Hirst (15) as its source.] The following comments apply:

1. None of the various studies has confirmed this finding;
2. For 1965, Hirst determined the figure to be 450 Btu/ton mile for barge; no explanation is offered to justify the 1970 figure; and
3. Hirst regards the 1970 figure as "particularly open to question"; his footnote "e" attached to the figure reads (15):

> This research effort was complicated by data inconsistencies, different definitions used by various agencies, missing data, and unexplained temporal variations in data. Therefore, we often found it necessary to approximate, extrapolate, interpolate, and even guess values. Those numbers in the tables that are particularly open to question have an "e" following the number. Because of these data limitations, results presented here should be used cautiously.

Last, in an article by M.L. Smith (16), barge miles are alleged to exceed rail miles by 55 percent in a study of 36 origins and 35 destinations--a combination of 1260 city pairs--on selected movements. The comments on this source are as follows:

1. Rail route mileage is understated; Missouri Pacific shows the "logical" rail route to be 8.3 percent greater than the rail short-line distance; the ICC study (11, p. 13) from its sample shows actual routings to be 16.4 percent greater than short-line routings;
2. Proper comparison would be (a) to compare circuity on actual movements and relate it to traffic density and (b) to use the common basis of the Great Circle distance for both rail and barge circuity; and
3. The city pairs chosen are far from representative; the U.S. Army Corps of Engineers, for example, reports average haul on the inland system to be 381.7 miles; the average haul in the Missouri Pacific compilation is 1124.7 miles, which is nearly three times greater (2, Table 3, p. 94).

The Oak Ridge National Laboratory (ORNL) calculation for all inland water modes, 440 Btu/ton mile (8), seems somewhat high. The same method was used for inland barge as for the Great Lakes. The "generic ship" chosen was of 1350 hp; this compares unfavorably with the 4000- to 10 000-hp towboats now ordinarily used, which are much more energy-efficient than their smaller counterparts. L.E.

Sutton of Dravo Mechling reported in a speech at the International Trade Mart in New Orleans on May 5, 1980, that from 1967 to 1977, barge demand went up 60 percent (from 174 billion ton miles to 277 billion ton miles), that the number of towboats increased only 10 percent (from 4000 to 4400), but that the total towboat horsepower doubled (from 3 million hp to a little more than 6 million hp) (10).

There are additional difficulties with the ORNL estimate of 440 Btu/ton mile. In the 1979 ORNL study (8), an earlier study is relied on (4). In the earlier study, it is stated that energy consumption for inland waterways was calculated by using the Great-Lakes-sector methodology, yet ORNL reports using coastal-sector methodology to compute inland water energy intensity. In addition, estimates for tug or barge (278 Btu/ton mile) and tanker (355 Btu/ton mile) are reversed from the earlier study to the later ORNL study [compare Table IV-4, p. IV-4 (4), with Table 4.9, p. 4-11 (8)]. The effect of these seeming inconsistencies on the estimate of 440 Btu/ton mile for all inland water modes is not known.

Nevertheless, data on average barge energy intensiveness both from analytic models and supplied by questionnaire from the operators show a range of 270 Btu/route ton mile to 350 Btu/route ton mile, which is well below the range of 650 Btu/route ton mile to 750 Btu/route ton mile for rail.

Table 1. Work performed compared with fuel consumed.

Mode	Work Performed: Ton Miles (billions)	Work Performed: 1 Ton of Freight Moved per Gallon (miles)	Fuel Consumed: Trillion Btu	Fuel Consumed: Btu per Ton Mile
Rail	784	202	538	686
Highway	470	59.2	1101	2343
Waterway[a]	178	514	48	270
Pipeline	476	492	134	282

[a]Excludes Great Lakes and domestic deep-draft shipping.

COMPARING CIRCUITY

A relevant question in making comparisons of energy efficiency is whether the water route is significantly more circuitous than the rail route between the same city pairs. The answer is that sometimes it is and sometimes it is not. Towboats follow winding rivers, but railroads are built along the easiest grades. These are seldom straight lines and even sometimes follow what the railroads call the "water-level route" along the riverbanks. The best way through a mountain range is that which follows the easiest grade. It is seldom "the way the crow flies."

Whereas barges always follow rivers, railroads do not necessarily route their traffic over the shortest possible rail route. More than 70 percent of all rail traffic is interlined with other railroads. The average shipment moves on the trackage of more than three railroads (17, p. 183). There is a strong economic incentive for a railroad to keep a given shipment for as long a distance as possible before turning it over at an interchange point, since the longer the distance that freight travels on a single railroad's lines, the greater the revenue is to that railroad. As a practical matter, therefore, the rail short-line distance must be adjusted to take into account the way in which the traffic actually moves.

All these variables can be accommodated in order to arrive at a comparison of distances actually traveled by the freight that uses the Great-Circle distance as the common measure for comparison purposes. A Great-Circle distance is that measured between origin and destination, and the degree of circuity is calculated from that for each mode. The values in Table 2 show that, on the average, barge is somewhat more circuitous than rail but not nearly enough for rail to overcome barge's superior route-mile energy efficiency.

It is of course perfectly possible to imagine water circuities that are much greater than those shown in Table 3. One railroad made a list of such possible routings, which included Sioux City, Iowa, to Brownsville, Texas, via the Missouri River, New Orleans, and the Gulf Intracoastal Waterway, and

Figure 1. Relative energy efficiencies: truck, rail, and barge.

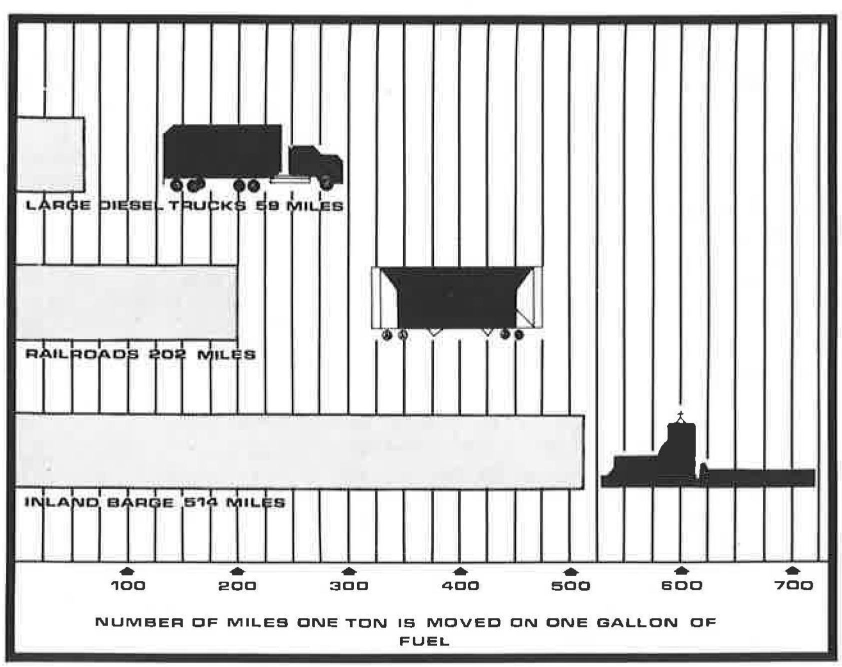

Table 2. Energy intensity: rail and domestic water transportation.

Study and Mode	Btu per Route Ton Mile	Miles 1 Ton Moved per Gallon
Rail		
Oak Ridge National Laboratory (ORNL) (1979)[a]	670	207
ICC adjustment[b]	780	178
DOT (1976)[c]	687	202
Twelve railroads from ICC reports (1976)[d]	644	215
DOT (1979)[e]	686	202
Domestic Water Transportation		
ORNL (1979), all domestic water[f]	440	315
DOT (1976)[g]		
Barge average	272	510
Lower Mississippi		
Upstream	276	503
Downstream	103	1347
One inland barge operator		
Lower Mississippi downstream[h]	141	984
Inland barge operators		
27, 1977 avg[i]	352	394
2[j]		
All waterways	326	425
Lower Mississippi	278	499
Ohio	329	421
Illinois	366	379
DOT (1979)[k]	270	514
Thirty samples: Great Lakes self-unloading[l]		
Lake Superior, lower lakes	261	531
Lake Michigan	240	578
General trades	215	645

[a] Data are for 1977 (8, Table S.8, p. S-9).
[b] Rail routing adjusted by ICC study (11, p. 13).
[c] Data are for 1972 (12, Table II-8, p. II.21).
[d] Study by Eastman (9, p. 220).
[e] Data are for 1972 (10, Tables 4-1, 4-2, and 4-3, pp. 31, 33, and 34).
[f] Data are for 1977 (8, Table S.4, p. S-4).
[g] Data are for 1972 (12, Tables II.9 and II.10, pp. II.28 and II.29).
[h] According to American Commercial Lines, Inc., Sept. 21, 1979.
[i] From responses to American Waterways Operators, Inc., questionnaire to members, Dec. 17, 1979. Approximately 36 percent of inland barge traffic is reported.
[j] From responses to Water Transport Association (WTA) questionnaire to members, Nov. 30, 1979.
[k] Data are for 1972 (10, Tables 4-1, 4-2, and 4-3, pp. 31, 33, and 34) but exclude Great Lakes and domestic deep-draft vessels.
[l] From responses to WTA questionnaire, Nov. 30, 1979. Data are for 1979. Miles 1 ton moved per gallon based on distillate fuel oil; based on residual fuel oil (149 700 Btu/gal), values are 573, 624, and 696 miles 1 ton moved per gallon, respectively.

added up all the possible barge routings to compare barge circuity with that of rail. Needless to say, not much traffic moves from Sioux City to Brownsville. This study is also flawed because the average barge length of haul calculated was 1125 miles, whereas the U.S. Army Corps of Engineers reported the average length of haul on the inland waterway system in 1977 to be about one-third that distance, or 382 miles. Therefore, the model could not be used as representative of the manner in which barge traffic actually moves (16; 2, Table 3, p. 94).

A sounder approach is to use the Corps of Engineers' analysis of traffic densities by river segment as shown in Figure 2. There the width of the river segment shown portrays the tonnage carried on that segment, both upward and downward. About 69 percent of all waterway traffic is between Minneapolis and New Orleans, about 65 percent between St. Louis and New Orleans, and an additional substantial amount on the Lower Ohio River (based on ton miles, 1977) (2, pp. 25 and 28). The greatest future growth of waterway traffic is in grain and fuel on these same segments of the river (18, pp. 147 and 161). Circuities on these particular stretches of the river provide a useful guide to perhaps three-quarters of all river traffic. As shown in Table 3, the actual city-pair circuity for going by barge between Minneapolis and New Orleans (1.61) and that between St. Louis and Baton Rouge (1.59) are slightly lower than that reported by barge operators for these river segments whose calculations are for actual operations between their terminals on the river.

Rail and Water Grain Shipments to Gulf

How this all works out in actual practice is seen by comparing typical rail routings with those for barge on the heavy movements of grains for export from the upper Midwest to ports on the Gulf of Mexico. This comparison demonstrates that after circuity has been taken into account for both modes, barge is considerably more fuel-efficient than rail. As shown in Table 4, water is from 45.9 percent to 130.7 percent more energy-efficient than is rail, depending on the rail routing used.

Coal Supplies for Tennessee Valley Authority

A study of the routings of 25 million tons of coal supplied to the Tennessee Valley Authority (TVA) in 1976 showed average rail circuity of 1.736, somewhat less than the average barge circuity of 1.991 [Table 5 (9, p. 216)]. No attempt was made to determine how rail traffic actually moved; the railroads were given the benefit of the rail short-line distance in every case. By using these circuities and estimates of Btu/route ton mile energy intensities developed for DOE, barge energy efficiency was found to be superior to that of rail by 30 to more than 100 percent (9, p. 209).

ACCESS TO RAIL AND BARGE SYSTEMS

Attention has been called to the comparative energy efficiency of competitive rail and barge shipments, particularly energy used in other than the long-haul movement (16, p. 6). Grain does not grow either in the streets of St. Louis, where grain is loaded into barges, or in the streets of Kansas City, where grain is loaded into unit trains. For high-volume movements by barge and unit train, there is often a prior or subsequent haul by another mode.

For the barge industry, this is frequently the rail or pipeline mode. On coal shipments, which represent 25 percent of all barge tonnage moved on the inland waterways, there are 70 rail-water interchanges on the inland waterway system (20). For barge petroleum movements, which account for another 25 percent of water tonnage, access is frequently by pipeline. Trucks feed both rail and water modes and are more energy-intensive than either. From the analysis of Appalachian coal movements summarized below (21, p. 6-4), truck was used 57.7 percent by the rail mode compared with 42.9 percent by the water mode for gathering traffic.

Mode	Short Tons (000s)	Percentage of Total
Rail only	118 893	
Truck and rail	162 305	
Total rail	281 198	73.9
Water only	20 172	
Truck and water	15 137	
Total water	35 309	9.3
Truck only	43 692	11.5
Other	20 126	5.3
Grand total	380 325	

INDIRECT ENERGY USE

A recent study by ORNL for DOE calls attention to the energy consumed in the manufacture of vehicles, the construction of necessary facilities, and the maintenance and upgrading of such facilities by the various modes (8, p. 2-9). No precise definitions

Table 3. Circuity comparisons.

Study and Mode	Btu per Route Ton Mile	Circuity[a]	Btu per Ton Mile[b]
ORNL (1979)			
Rail			
Short-line distance[c]	670	1.32	880
Actual distance moved[d]	670	1.54	1030
All domestic water	440	1.59	700
Two inland barge operators[e]			
All waterways	326	1.74	567
Lower Mississippi	278	1.74	484
Ohio	329	1.79	589
Illinois	366	1.59	582
Minneapolis to New Orleans, barge[f]		1.61	
St. Louis to Baton Rouge, barge[g]		1.59	
Thirty samples: Great Lakes self-unloading[h]			
Lake Superior, lower lakes	261	1.26	329
Lake Michigan	240	1.00	240
General trades	215	1.32	284

[a] No circuity, 1.0.
[b] Adjusted for circuity.
[c] Data are for 1977 (8, Table S.8, p. S-9). Data on rail short-line distance are as reported in ORNL report (8); Btu/ton mile adjusted for circuity for actual distance moved rounded to nearest ton, following ORNL report (8).
[d] Rail routing adjusted by ICC study (11, p. 13).
[e] From responses to WTA questionnaire to members, Nov. 30, 1979; Btu/route ton mile are for 1978; circuity data reported by only one carrier were applied to average for two carriers.
[f] Lambert's Landing at mile 839.0 (latitude 44° 57" north; longitude 93° 6" west) to St. Andrew's Street Wharf at mile 96.8 (latitude 29° 56" north; longitude 90° 4" west).
[g] Municipal Dock at mile 181.7 (latitude 38° 39" north; longitude 90° 11" west) to Greater Baton Rouge Port Commission docks at mile 229.0 (latitude 30° 25" north; longitude 91° 10" west).
[h] From responses to WTA questionnaire to members, Nov. 30, 1979. Data are for 1979.

or quantifications of these types of energy by mode are available. However, it would appear from the estimates shown in the study that the indirect energy required by the rail mode is greater as a percentage of their direct energy use than is the case for the water mode. Indirect energy use, shown below as the percentage of direct energy use, is 116.7 percent for rail and 85.7 percent for marine transportation (22, p. 2-9):

Mode	Indirect Energy Use (%)
Air	63.2
Automobile	37.9
Bus	100.0
Marine	85.7
Pipeline	7.1
Rail	116.7
Truck	42.9
Total	42.0

CONCLUSION

Whereas it seems clear that the water mode is more energy-efficient than the rail mode, it is also apparent that the rail, pipeline, and water modes, which account for 75 percent of the intercity freight load, are all remarkably efficient in their use of energy. By comparison, airplanes and trucks are less energy-efficient. The ORNL study (8) reports the route-mile energy intensity of all-cargo

Figure 2. Inland freight tonnage on Mississippi River system and Gulf Intracoastal Waterway.

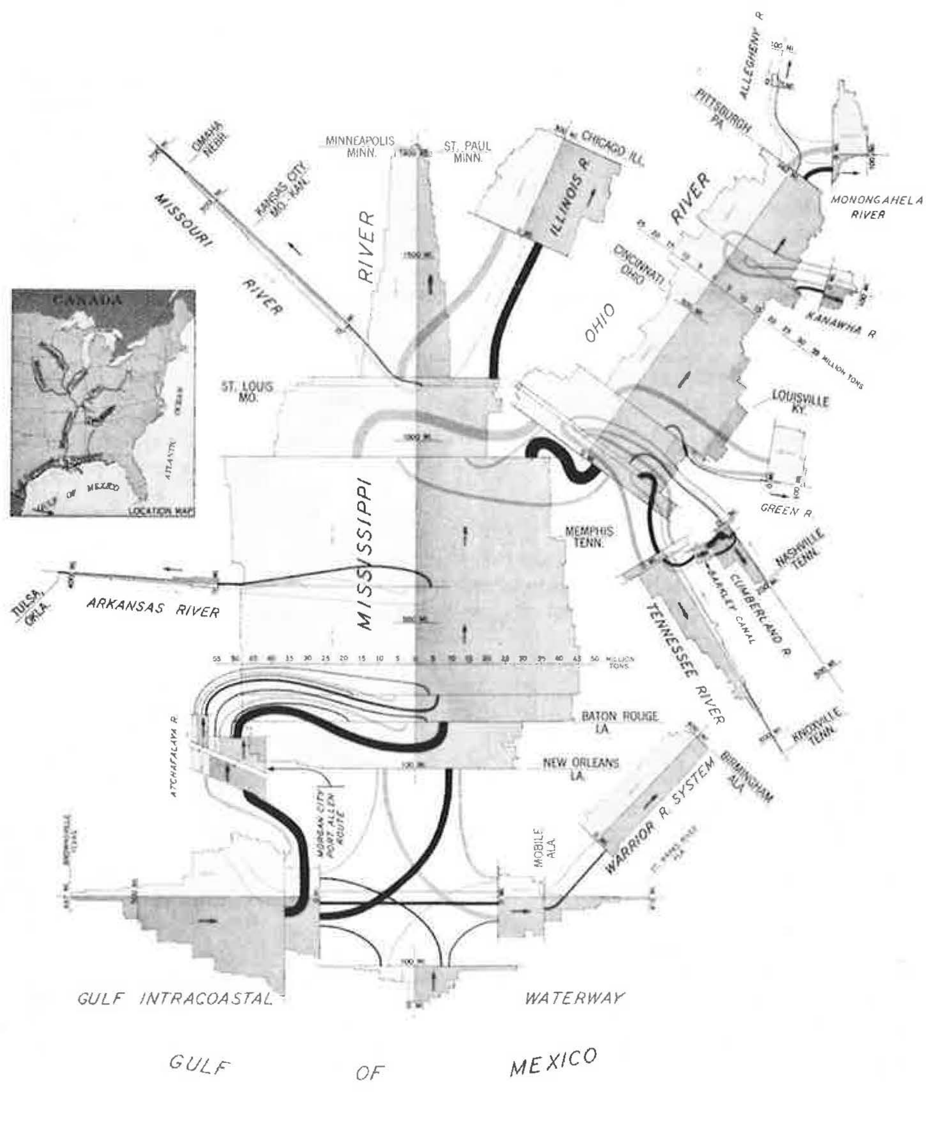

Table 4. Relative circuity and energy efficiency: rail and water grain shipments to Gulf of Mexico.

Route	Energy Intensity: Route Mile (Btu/ton mile)	Energy Intensity: Great Circle Mile (Btu/ton mile)	Mileage	Circuity	Higher Energy Efficiency of Water (%)
Minneapolis-New Orleans Great-Circle distance			1051	1.00	
Inland water	326[a]	525	1696	1.61	
Alternative rail routings[b]					
BN/MILW/SOO-ICG	644[c]	766	1250	1.19	45.9
CNW-MP	644	882	1441	1.37	68.0
MILW-KCS-LA	644	895	1467	1.39	70.5
CNW-MP	644	921	1504	1.43	75.4
CNW-MKT-LA	644	927	1517	1.44	76.6
CNW-SLSF-LA	644	959	1562	1.49	82.7
RI-LA	644	979	1602	1.52	86.5
MILW-MKT-TPMP	644	992	1621	1.54	88.9
RI-TPMP	644	1050	1716	1.63	100.0
MILW-MKT-TCT	644	1211	1976	1.88	130.7

[a]Average of two inland barge operators from all waterways, responses to WTA questionnaire to members, Nov. 30, 1979.
[b]Rail routings are taken from Upper Mississippi Waterway Association study (19, p. 75).
[c]Average of 12 railroads filing at ICC (9, p. 220).

Notes: Average inland water and rail energy intensities have been used because these estimates are supported by the most available data. Water would be downstream and grain would be in unit trains, both of lower energy intensity than the mode average. Railroad names are abbreviated as follows: BN, Burlington Northern, Inc.; MILW, Milwaukee Road; SOO, Soo Line Railroad Co.; ICG, Illinois Central Gulf Railroad; CNW, Chicago and North Western Transportation Co.; MP, Missouri Pacific Railroad Co.; KCS, Kansas City Southern Railway Co.; MKT, Missouri-Kansas-Texas Railroad Co.; LA, Louisiana and Arkansas Railway Co.; SLSF, St. Louis-San Francisco Railway Co.; RI, Chicago, Rock Island and Pacific Railroad Co.; TPMP, Texas Pacific-Missouri Pacific Terminal Railroad of New Orleans; and TCT, Toledo City Terminal Railroad Co.

Table 5. Circuity of all-water barge and rail coal shipments to TVA.

Mode and Facility	Tons (000s)	Straight-Line Ton Miles (000 000s)	Actual Ton Miles (000 000s)	Circuity
Barge				
Watts Bar	118.9	20.541	93.574	4.575
Johnsonville	2 788.0	529.770	992.732	1.874
Widows Creek	495.2	11.390	11.390	1.000
Colbert	31.7	5.801	15.691	2.705
Shawnee	185.1	30.165	55.830	1.851
Allen	2 576.7	672.516	1419.601	2.111
Cumberland	4 651.7	450.163	836.189	1.857
Total or avg	10 847.3	1720.256	3425.007	1.991
Rail				
Johnsonville	837.2	149.810	268.950	1.795
Widows Creek	2 594.6	520.051	803.212	1.544
Kingston	1 051.2	90.223	207.131	2.296
Shawnee	3 912.9	271.082	368.960	1.361
Gallatin	2 212.5	263.128	435.691	1.656
John Sevier	1 869.4	201.495	408.026	2.025
Bull Run	1 891.1	159.485	381.037	2.389
Total or avg	14 368.9	1655.274	2873.007	1.736

domestic aircraft in 1976 as 25.360 Btu/route ton mile and the energy intensity of large diesel trucks as 2.740 Btu/route ton mile. Needless to say, rail, water, and pipeline do not provide the type of transportation services offered by airlines and trucks.

The energy intensity for pipelines shown in Table 1 (282 Btu/ton mile) is for petroleum (both crude and product). Natural-gas pipelines are powered mostly by natural gas and petroleum pipeline mostly by electricity (5, p. 2-15). A recent study of two pipelines powered by electricity reports energy intensities of 283 Btu/ton mile for Colonial and 362 Btu/ton mile for Plantation (22, p. 38).

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Transportation of Coal to Seaports via Mid-America Inland Waterway System

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The mid-America inland waterway system has long been recognized as one of the basic means for the movement of domestic coal. Yet, until the recent steam-coal export boom, insufficient attention had been paid to the economic advantages of shipping coal by river for export transshipment at Gulf Coast ports. The ports of Mobile in Alabama and New Orleans in Louisiana combined to handle 2.7 million tons of export coal in 1979, according to the U.S. Department of Commerce records. These two ports, however, offer much greater capacity than current demand requires. In addition, other Gulf Coast ports are exploring the potential for coal export, most notably Galveston, Texas.

The current congestion being experienced at the ports of Hampton Roads and Baltimore has dramatically altered the way in which the U.S. coal industry views itself within the context of world coal supply and demand. Hundreds of millions of dollars have been committed for the construction of new coal-loading terminals at these two ports and others located along the Atlantic Seaboard. Coal companies, previously involved with mining coal only, are now assisting financially in the development of new and/or expanded coal terminals. These commitments have received extensive documentation and will not be repeated here (1-3).

Likewise, the ports of Mobile and New Orleans and the entire mid-America inland waterway system are responding to the unprecedented demand for U.S. mined steam coal. In an effort to report the development of this portion of America's coal-handling capacity, this paper has three major objectives:

1. To place the mid-America inland waterway movement of coal for export in a broad domestic context of total U.S. coal movements for export;
2. To define the network of coal movement on mid-America inland waterways, including major points of origin; and
3. To describe the existing facilities and plans for expansion at the two leading Gulf Coast ports of New Orleans and Mobile, which receive a portion of their export coal via mid-American inland waterways.

RELATIONSHIP OF MID-AMERICA COAL EXPORTS TO TOTAL U.S. EXPORTS

Historically, the United States has exported a fairly stable level of bituminous coal since 1974 [Table 1 (4, pp. II-12 and II-16)]. With the exception of 1978, when a low of approximately 40 million tons was exported, a generally consistent level of between 54 million and 66 million tons of coal have left U.S. ports for consumption overseas. In 1977, approximately 78 percent of total coal exports was the metallurgical variety (met coal) processed into coke for use in steel production. The remaining 22 percent was steam coal used in the conversion of electricity, heat, steam, etc. (5). With the growing demand for U.S. steam coal, the relative shares of met coal and steam coal are expected to balance; steam coal will assume the larger share by the year 2000. The often-quoted Massachusetts Institute of Technology (MIT) text Coal: Bridge to the Future (5) offers two likely scenarios of future coal export demand. In scenario A, total exports are estimated at 125 million tons by the year 2000; steam coal accounts for 65 million tons, and met coal accounts for the remaining 60 million tons. In scenario B, a total of 200 million tons is forecast for export; steam coal represents 130 million tons and met coal, 70 million tons. Thus, in the minds of the MIT analysts, the volume of met coal could remain in a fairly well-defined range between 60 and 70 million tons for export by the year 2000. The steam-coal export market, on the

Table 1. U.S. exports of bituminous coal.

Seaport	Short Tons Exported (000s) 1974	1975	1976	1977	1978	1979
Hampton Roads	35 745	36 952	32 000	24 244	15 396	33 753
Baltimore	5 949	6 769	6 327	7 055	5 887	9 141
Philadelphia	1 431	802	447	187	90	55
New Orleans	992	1 292	1 297	1 432	1 388	1 410
Mobile	1 746	2 745	2 755	3 611	1 848	1 284
Great Lakes	14 063	17 108	16 580	17 158	15 214	19 140
Total	59 926	65 668	59 406	53 687	39 825	64 783

other hand, is not so clearly determined and could be subject to continued pressure from rising oil prices determined by the Organization of Petroleum Exporting Countries (OPEC). In this case, a range between 65 and 130 million tons was offered.

In 1979, 65 million tons of coal were exported from the United States. Of this total, the ports of Hampton Roads and Baltimore combined to account for 43 million tons, or 66 percent of total U.S. exports. Several Great Lakes ports are also handling considerable volumes of export coal to Canada. Most noted among these are the loading terminals at the ports of Ashtabula, Ohio; Toledo and Sandusky, Ohio; and Port Huron, Michigan. The Great Lakes ports as a whole exported 19 million tons to Canada in 1979. During this same year, the port of Philadelphia handled 0.6 million tons of coal for export, according to U.S. Department of Commerce statistics.

Obviously, preliminary data for 1980 reflect export tonnages moving out of ports that had previously never handled coal. The ports of New York, Wilmington, Long Beach, and others are all moving coal, sometimes in primitive and tedious fashions. For example, at one port where direct rail-to-vessel conveyor-belt equipment is not available, the logistics of loading the coal for export are as follows: (a) coal from rail cars is loaded into open-top heavy-duty trucks for delivery to the port apron area, (b) coal is dumped in piles onto the apron from trucks, and (c) grab-bucket crane equipment loads coal bucket by bucket into the berthed vessel. The approximate loading time for a small-bulk vessel of approximately 30 000 tons dead weight can be 7-10 days, or 3 tons/month.

The Gulf Coast ports of New Orleans and Mobile handled 1.4 million tons and 1.3 million tons of coal, respectively, for export in 1979, according to U.S. Department of Commerce statistics. In the case of New Orleans, the 1979 total was close to the largest handled over the past six years. For Mobile, the 1979 figure was the smallest level of activity since 1974. By 1986, the Tennessee-Tombigbee Waterway is expected to generate additional coal exports through Mobile. The source of this coal will be mines in Tennessee, north Alabama, and western Kentucky. Some of this coal now moves through New Orleans. The balance will be coal from new mines that will be opened in the future. Coal exports generated by the Tennessee-Tombigbee Waterway are expected to amount to 50 percent of the total coal exports through Mobile.

Table 2 (6) shows the relationship between total U.S. waterborne commerce and total waterborne coal movements. As shown, since 1972, the percentage of waterborne coal movements has ranged from 12.9 to 9.2 percent of total U.S. waterborne commerce in terms of gross tonnage. During the same time, the percentage of coal exports has ranged from 2 to 3.9 percent of total U.S. waterborne commerce. Recall that the ports of Mobile and New Orleans accounted for approximately 2.7 million tons of export coal in 1979, or 4.2 percent of total coal exports in that year.

Table 2. Total U.S. waterborne commerce, coal movements, and internal coal movements.

Year	Short Tons (000 000s) Total U.S. Waterborne Commerce	Total Coal	Coal Exports	Coal Exports as Percentage of Total Coal	Percentage of Total U.S. Waterborne Commerce: Total Coal	Coal Exports
1978	2021.3	185.9	40.3	21.7	9.2	2.0
1977	1908.2	212.0	53.9	25.4	11.1	2.8
1976	1835.0	215.1	59.8	27.8	11.7	3.3
1975	1695.0	219.0	65.3	29.8	12.9	3.9
1974	1746.8	208.5	61.6	29.5	11.9	3.5
1973	1761.6	197.7	53.0	26.8	11.2	3.0
1972	1616.8	204.9	55.9	27.3	12.7	3.5

Note: Coal export data for this table will not agree in all cases with coal export totals shown in Table 1, since information in Table 1 is from the U.S. Department of Commerce and the data in Table 2 are from the U.S. Army Corps of Engineers.

In more detail, Table 3 (6) shows the relationship between total U.S. waterborne coal movements and several subcategories of foreign and domestic coal movements. Foreign tonnage includes exports as well as imports. According to the U.S. Army Corps of Engineers' statistics, the United States as a whole imported 1.9 million tons of coal in 1978. [These figures do not include imports of refined coking coals. Since 1972, imports of coke have been rising at an alarming rate due in large part to the decline of the domestic coke production capacity (7).] Total domestic waterborne coal movements were 143.8 million tons in 1978. Internal domestic movements represented the greatest volume, 114.6 million tons, followed by lakewise, coastwise, and local movements at 22.9 million tons, 3.3 million tons, and 3.0 million tons, respectively. (For a definition of these terms, see any issue of the U.S. Army Corps of Engineers Waterborne Commerce Statistics, introductory material.)

With this information as background, the next section describes the major points of origin for coal that moves along the mid-America waterway system. Emphasis is placed on the terminals located on the Black Warrior River that serve Mobile and those on the Ohio River that serve New Orleans.

DEFINITION OF NETWORK OF COAL MOVEMENTS ON MID-AMERICA INLAND WATERWAYS

Physical Characteristics of Waterway System

The waterway system of the United States consists of 26 000 miles of commercial navigable waterways, the shipping lanes of the Great Lakes and coastal trade routes, and the more than 200 commercial inland and coastal harbors and ports. The inland system and the Great Lakes are improved by 265 locks, channel alignments, bank-stabilization modifications, and cutoffs. They are maintained by periodic dredging, cleaning, and snagging of the channels. The U.S. Army Corps of Engineers operates most of the locks

Table 3. Foreign and domestic waterborne movements of coal and lignite.

	Short Tons (000 000s)							
	Total U.S. Waterborne	Foreign		Domestic				
Year	Coal	Imports	Exports	Total	Coastwise	Lakewise	Internal	Local
1978	185.9	1.9	40.3	143.8	3.3	22.9	114.6	3.0
1977	212.0	1.7	53.9	156.3	3.7	22.2	127.6	2.8
1976	215.1	1.2	59.8	154.2	2.8	21.6	128.0	1.8
1975	219.0	0.9	65.3	152.8	3.5	21.8	125.3	2.2
1974	208.5	2.1	61.6	144.8	4.0	21.7	116.4	2.7
1973	197.7	0.1	53.0	144.5	3.6	23.8	114.1	3.1
1972	204.9	0.0	55.9	149.0	3.6	25.2	118.2	2.0

Notes: Coal export data for this table will not agree in all cases with coal export totals shown in Table 1, since information in Table 1 is from the U.S. Department of Commerce and the data in Table 3 are from the U.S. Army Corps of Engineers.
Row totals may not add due to rounding.

and maintains most of the improved waterways and harbors (8).

No obvious constraints exist for water movement of Western coal, which is first transported by rail to the middle Mississippi River. However, various types of constraints generally appear for Ohio River movements of West Virginia, Kentucky, and Tennessee coal. Figure 1 depicts the major waterways for the United States. Table 4 (9) gives the characteristics of the selected locks on the system.

Tennessee River

Coal from the southern Appalachian area in eastern Tennessee could move on the Tennessee River to the lower Ohio River near Peducah, Kentucky, proceed through Locks and Dams 52 and 53 on the Ohio River, then proceed from Cairo, Illinois, on the lower Mississippi River (which is free from locks) to New Orleans. Locks on the Tennessee River upstream from Chattanooga would represent a major constraint to waterway commerce because the Chickamauga Lock would have a reserve capacity of less than 1 million tons/year (see Table 4). The most capacity-constrained lock on the Tennessee River between Chattanooga and its confluence with the Ohio River is the Kentucky Lock and Dam, which in 1976 had a reserve capacity of only 4 million tons. Tennessee Consolidated Coal operates a coal-loading terminal at Halesbar. Coal is trucked from distances of approximately 30-35 miles and loaded directly onto barges.

Ohio River

The Ohio River and its tributaries can best be described by dividing them into an upper and a lower system. The lower system extends from Cincinnati, Ohio, to the mouth of the river, where it enters the Mississippi River at Cairo, Illinois. The upper Ohio system is between Cincinnati and Pittsburgh, Pennsylvania.

Lower Ohio River

The primary constraint on the lower Ohio River is the McAlpine Lock at Louisville, Kentucky. In 1976, this lock had an estimated reserve capacity of about 23 million tons/year. Capacity for other locks on the Ohio River that are similar in size has been estimated to be 95 million tons. The lower capacity at the McAlpine Lock is attributable to the congestion problems experienced in the approach canal. The Green River is a tributary to the lower Ohio River and serves the coal-producing region in western Kentucky. The Green River has substantial reserve lock capacity downstream from Rochester; the reserve capacity is 55 million tons/year and the 1976 tonnage was 14 million tons for both Lock and Dam 1 and Lock and Dam 2. Owensboro, Kentucky, is the location of several barge-loading terminals, at approximately mile 756. Coal is trucked in from southern Indiana and Kentucky, stockpiled, and conveyed onto barges.

Upper Ohio River

The upper Ohio River serves coal-mining regions in northwestern West Virginia and southwestern Pennsylvania. Gallipolis on the upper Ohio River (near Huntington, West Virginia) represents a potential constraint in that it had a 1976 reserve capacity of less than 8 million tons. Studies to increase the capacity of the Gallipolis locks are under way. In addition, locks at Emsworth, Dashields, and Montgomery and the upper Ohio River below Pittsburgh are all potential candidates for capacity overloads if there were any significant increase in coal movement. These locks are represented by the characteristics of the Emsworth Lock and Dam, which had a reserve capacity of 11 million tons in 1976.

The Kanawha River flows into the Ohio River immediately upstream from the Gallipolis Locks and Dam and serves the coal-mining region in the vicinity of Charleston, West Virginia. The Kanawha River is constrained at Winfield Lock, which had a 1976 reserve capacity of about 7 million tons.

The Monongahela project extends upstream from Pittsburgh in Pennsylvania to Fairmont in West Virginia, and the most constraining lock would probably be Lock and Dam 3, which had a 1976 reserve capacity of 15 million tons. Locks 7 and 8 on the Monongahela River also constrain the coal traffic. The Gallipolis Locks on the upper Ohio River would represent a greater constraint to coal movements between West Virginia and New Orleans than those on the Monongahela.

Mississippi River

The Mississippi River between St. Louis in Missouri and New Orleans in Louisiana could easily carry many times its current level of commerce without being constrained. This section of the river is unobstructed by locks and dams. Inland navigation upstream from St. Louis, however, will face capacity problems if any substantial increase in coal movement occurs. Lock and Dam 26 on the Mississippi River above St. Louis represents an immediate constraint problem because traffic is rapidly approaching capacity. The estimated annual capacity of Lock and Dam 26 is 64 million tons and traffic levels had reached 58 million tons in 1976. A single 1200x110-ft lock is under construction and will replace the two existing locks. This new lock and dam will increase annual capacity by 9 million tons. The need for a second lock in the new structure for Lock

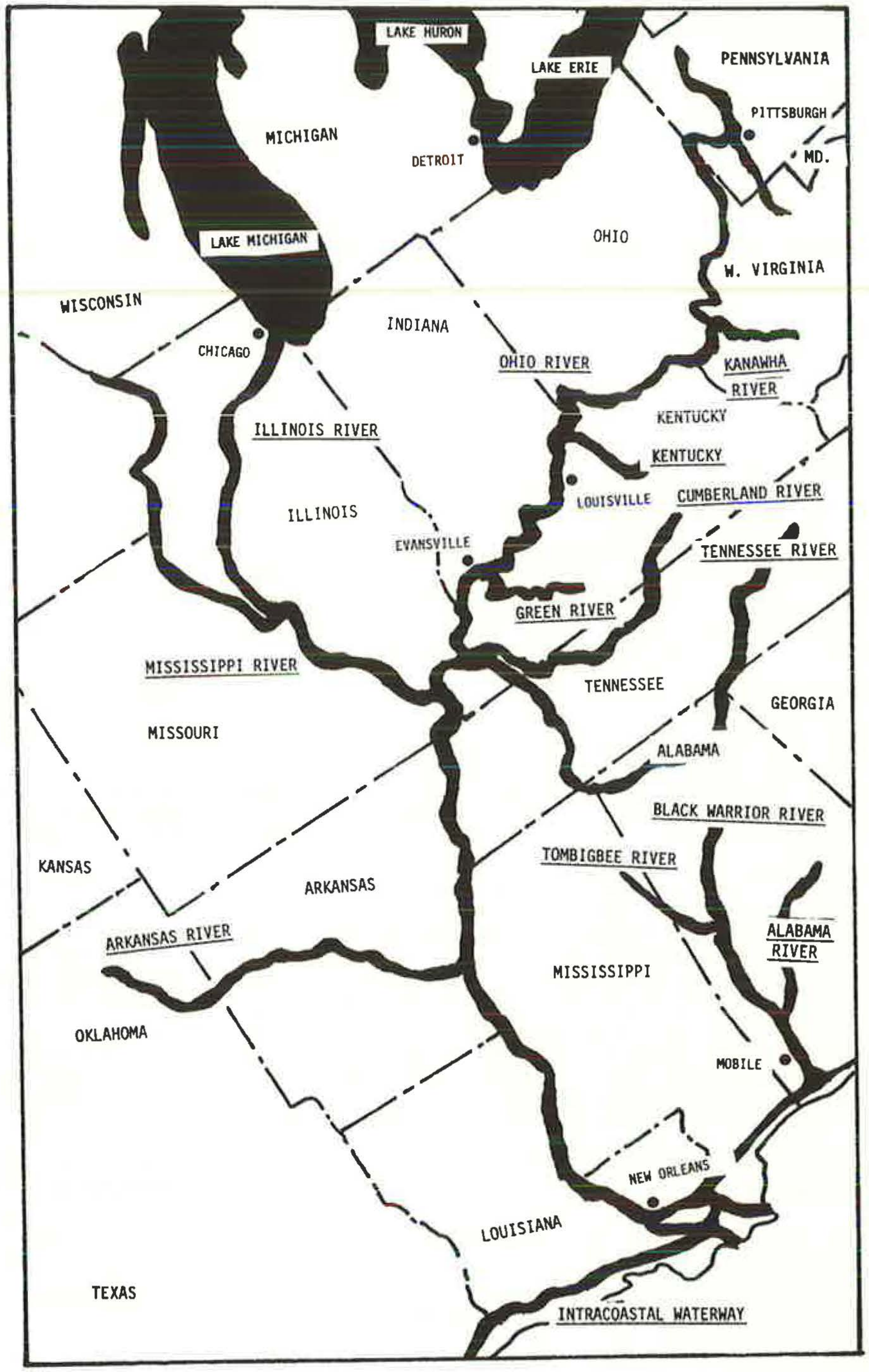


Figure 1. Mid-America inland waterway system.

and Dam 26 on the Mississippi River is also expected to be constrained. For example, Lock and Dam 25 had a 1976 reserve capacity of only 4 million tons.

Illinois River

The Illinois River connects the upper Mississippi River and the Great Lakes systems at Chicago. Historically, Illinois coal moved both north and south on the system. However, it is high-sulfur coal, and its use has been curbed. This waterway is already overloaded at seven locks, as illustrated by the Marseilles Lock (Table 4).

Kaskaskia River

The Kaskaskia River flows into the Mississippi River downstream from St. Louis. The Kaskaskia Valley, which lies in the heart of the Illinois coal-mining area, may have a great potential for increased coal mining. In 1976, the Kaskaskia River had substantial excess capacity.

Missouri River

The Missouri River has no locks and would appear to be relatively free from constraints; however, 9-ft channel depths are not dependable throughout the year. Controlling depths are only 8.5 ft below Boonville, Missouri, and navigation is shut down during winter and also when multipurpose water storage above Sioux City is insufficient to maintain minimum design flow.

Table 4. Characteristics of selected inland-waterway locks and dams.

River or Canal	Lock and Dam	Lock Size (ft)	Capacity (tons 000 000s) Annual[a]	1976 Traffic	Reserve in 1976
Upper Tennessee River	Chickamauga	360x60	5	4	1
Lower Tennessee River	Kentucky	600x110	30	26	4
Lower Ohio River	McAlpine	1200x110 600x110 360x56	67	44	23
Green River	1	600x84	55	14	41
Upper Ohio River	Gallipolis	600x110 360x110	49	41	8
Ohio River	Emsworth	600x110 360x56	37	26	11
Kanawha River	Winfield	360x56 360x56	20	13	7
Monongahela River	3	720x56 360x56	40	25	15
Upper Mississippi River	25	600x110	29	25	4
	26	600x110 360x110	64	58	6
Illinois River	Marseilles	600x110	26	26	0
Kaskaskia River	Kaskaskia	600x84	29	1	28
Arkansas River	Norrell	600x110	30	4	26
Inner Harbor navigation canal	Inner Harbor	640x75	26[b]	28	-2
Warrior River	W.B. Oliver	460x95	27	12	15
Welland Canal	1	730x80	75	64	11
Columbus-Snake River	Bonneville	500x76	9	6	3

[a]Capacity values are for "practical capacity," which is taken as 90 percent of net maximum technical capacity (for infinite queue length) after deductions for recreation and season.
[b]Based on limited data sample; lock is also used by ocean-going vessels.

Arkansas River

The Arkansas River project provides 9-ft channel depths to Catoosa, Oklahoma, near Tulsa. Coal traffic on the Arkansas from eastern Oklahoma has been increasing and the Arkansas River may have potential for substantial increases in coal traffic. The lock that had the most traffic on the Arkansas River (Norrell Lock) had a 1976 reserve capacity of 26 million tons.

Inner Harbor Lock

It is important to note that future coal movements down the Mississippi River destined for Mobile by way of the Inner Harbor Lock at New Orleans would be constrained by this lock. It was already overloaded in 1976 by 2 million tons.

Warrior River

Coal that moves from the Birmingham area to Mobile on the Warrior River would pass through several locks. The most constrained of these is the W.B. Oliver Lock.

Domestic Water Carriers

The inland waterways industry includes carrier firms of the order of 2000 or more. These range in size from operators of single vessels to operators of extensive fleets. The carriers are classified as regulated, exempt, and private. Some firms engage in activities in more than one of these categories.

The regulated carriers, which function under Interstate Commerce Commission jurisdiction, include common carriers, which extend service to all shippers without distinction, and contract carriers, which serve shippers under specific written contract. Many regulated carriers are subsidiaries of large companies, several of which have no direct connection with the inland waterways industry. Some of the regulated carriers also conduct unregulated operations. It should be noted that about 92 percent of all barge traffic is unregulated.

The rates charged by exempt carriers in the unregulated sector of the industry are not published, but they are often established by contract with the shipper. These exempt carriers are not required to report revenues, operating data, or financial information.

Private carriers operate primarily for the transport of their own products (usually coal, petroleum, chemicals, or grain), but they may also carry exempt commodities for others. Many of the private carriers own no towboats of their own but contract for towing service with regulated or exempt carriers.

Open-hopper barge carriers appear to be the most successful of any of the water-carrier groups; they exhibit the lowest operating expense level (83.6 percent) and the highest net income level (6.7 percent). Although these carriers have the greatest long-term debt percentage (66.1 percent), their low operating expenses allow for sufficient net income after interest expenses. Open-hopper barge carriers also show the largest expenditures for fuel (16.6 percent) and labor (20.6 percent), which reflects their prime emphasis on barge and towing operations and less emphasis on subsidiary activities. The ability of these firms to achieve high equipment utilization by negotiating long-term contracts for the movement of coal may partly explain their high profitability.

Coal is sold under long-term contracts as well as at spot prices. Historically, approximately 20 percent of the coal produced in the United States is sold on the spot market. This dichotomy in turn creates a contract market and a spot market for barge transportation. The barge carriers involved in coal trade participate in both contract and spot markets. In 1976, the percentage of spot movements reported varied among firms from 7 to 40 percent, which indicates that spot barge movements correspond closely to spot coal marketing.

EXISTING FACILITIES AND PLANS FOR EXPANSION AT GULF COAST PORTS THAT PLAN TO EXPORT COAL

The ports of Mobile and New Orleans occupy the most prominent position among the coal export transshipment facilities on the Gulf Coast. Other cities are in the process of evaluating the feasibility of coal-terminal development; however, detailed plans have not been presented at this time, except for Galveston.

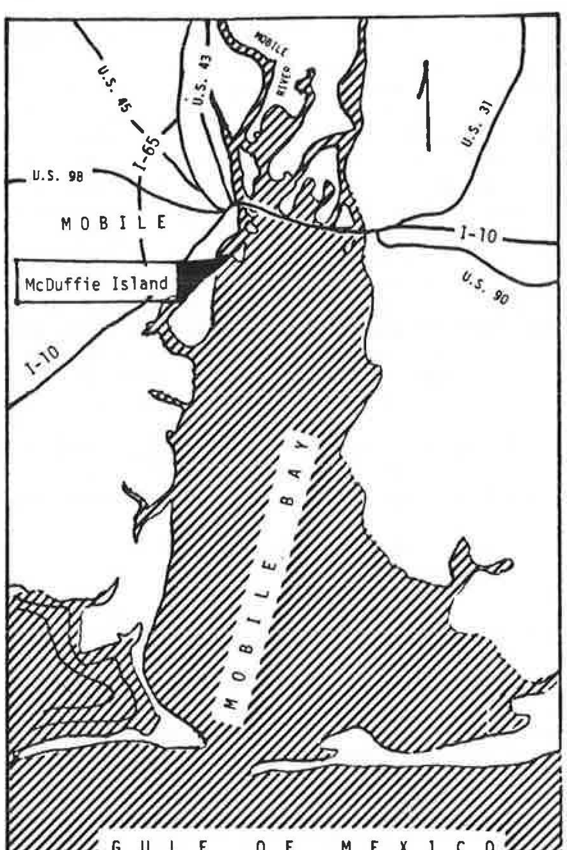
Mobile

The port of Mobile is located in the southwestern part of Alabama at the junction of the Mobile River and the head of Mobile Bay (Figure 2). The port is about 28 nautical miles north of the bay entrance from the Gulf of Mexico, and 170 nautical miles west of New Orleans. The port's principal waterfront facilities are located along the lower 5 miles of the Mobile River (10,11).

The outer harbor of Mobile consists of the deep-water channel that extends from the lower end of the Mobile Bay channel in the Gulf of Mexico to the mouth of the Mobile River. From the upper reach of the Mobile Bay channel, the Arlington channel leads northwest to a turning basin at the southwest end of Garrows Bend. Garrows Bend channel leads northeast from the turning basin and terminates south of the causeway that connects McDuffie Island with the mainland. McDuffie Island is just west of the Mobile Bay channel at the mouth of the Mobile River and is the location of all coal-exporting activities.

McDuffie Terminal is recognized as one of the most modern coal-handling facilities in the world. Most of the coal is now being mined in the north Alabama fields and shipped by barge to McDuffie for export. A small amount is being transported by rail

Figure 2. Port of Mobile.



for export. It is owned and operated by the Alabama State Docks Department, the only domestic coal-handling facility that involves direct public interest. It was placed into operation in January 1975 and incorporates the newest and most innovative approach to material handling and automatic barge unloading in the United States.

McDuffie Island is accessible from the mainland by a causeway and is served by the terminal railway of the Alabama State Docks Department. The island is adjoined on three sides by dedicated channels. The Mobile River channel on the east side is now authorized and maintained to a depth of 40 ft. The Arlington channel on the south side is authorized and maintained to a depth of 27 ft, and the Garrows Bend channel is authorized to a depth of 27 ft but has not been maintained since the construction of the causeway at the north end of the island (Figure 3).

The fact that McDuffie Island is south of the 44-ft-deep channel crossing of the tunnel for Interstate 10 places the facility in an advantageous position for the future handling of much larger bulk carriers. The U.S. Army Corps of Engineers in July 1979 held a public hearing in Mobile to address the matter of harbor improvements within the Mobile Harbor and ship channel. On finding economic justification, they rendered a plan for deepening the Mobile ship channel from a point south of the highway tunnels to the Gulf of Mexico from the current authorized depth of 40 ft to 55 ft.

The 40-ft channel depth now limits the size of vessels that call at Mobile to approximately 50 000 tons dead weight. Ships with capacities up to 100 000 tons dead weight with loaded drafts considerably in excess of 40 ft have called at Mobile. However, these larger vessels must leave the harbor only partly loaded due to existing channel-depth restrictions. The improvement and deepening of Mobile Harbor to a depth of 55 ft would permit vessels up to 120 000 tons dead weight to load fully at McDuffie.

The initial facilities constructed on McDuffie Island included an automatic barge unloader, railcar dump, truck dump, two storage pads, a stacker/reclaimer and material-handling conveyor system, ship dock, ship loader, offices, and control tower as well as back-up maintenance buildings and receiving tracks for rail cars (Figure 4). Expansion facilities will include an additional barge unloader, additional stacker/reclaimer, two additional storage pads, the construction of a loop track for handling unit trains of coal, and an integrated conveyor system.

The McDuffie terminals began operation in 1975 with the loading of 25 barges of coal on the vessel Errandale. Since that time, the plant has averaged more than 3 million tons/year of annual throughput, if exports and internal movements are counted. With the completion of the expansion, the projected annual throughput of the plant will be 7 million tons/year. However, the plant will have the capability of handling in excess of 10 million tons/year if needed.

Coal that arrives by water is carried almost exclusively in open-hopper barges 195 ft long, 35 ft wide, and 12 ft deep. The barges are of a more-or-less standard design and average loading is approximately 1400 tons of coal/barge. The barges are fleeted in protected waters on the west side of the island. Space is now adequate for approximately 35 barges adjacent to the barge unloader, and directly contiguous areas are available for expansion of the barge fleeting and holding operations.

The barges are brought into the fleeting area and moored by various towing companies that also remove

Figure 3. McDuffie Island and port of Mobile.

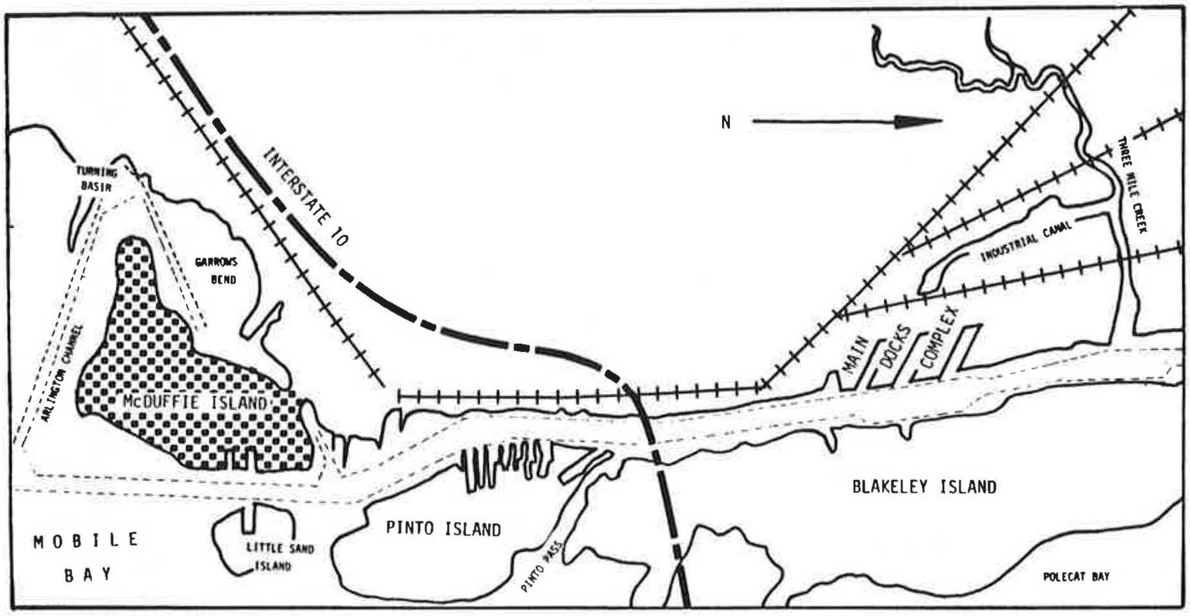
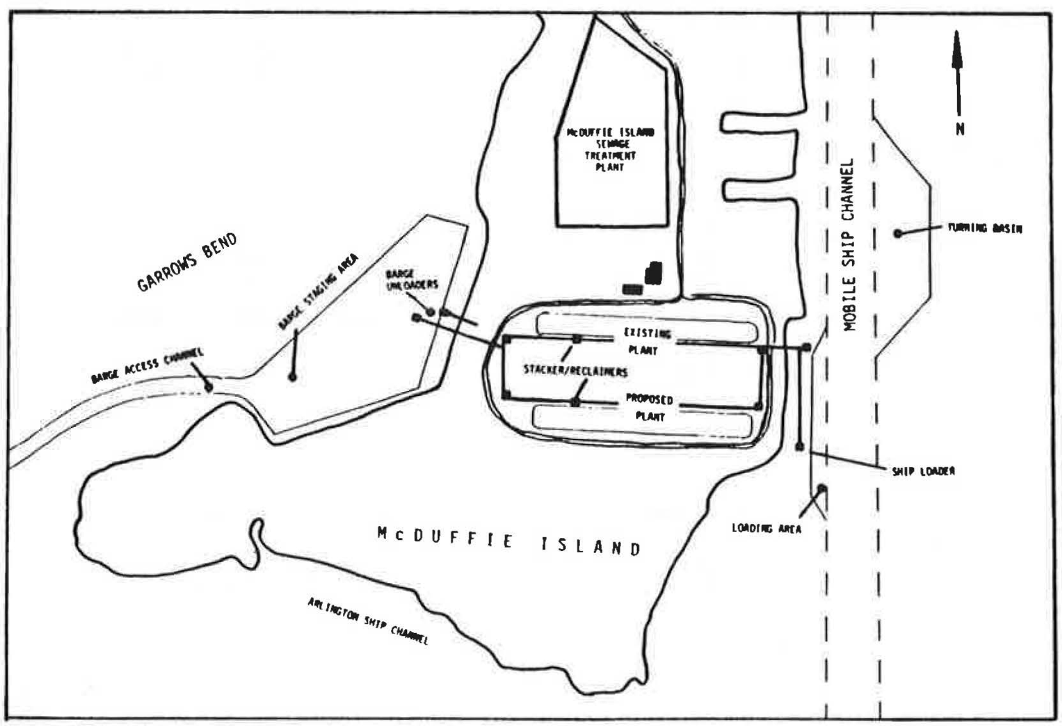


Figure 4. Physical layout of McDuffie Island coal-handling facilities.



the empty barges from the fleeting area. Movement of the barges within the fleeting area is accomplished by a work boat under contract to the various shippers. The barges are currently unloaded by a high-capacity, ladder-type bucket-elevator unloader. The bucket elevator remains stationary while the barge is moved back and forth beneath it to allow the unloader to remove the coal and place it on the conveyor system. The new barge unloader will be a similar design.

The average unloading rate, including time required to remove one barge and position another barge, is approximately 45 min, or a handling capacity of 10-11 barges/8-h shift. The coal removed from the barges is moved by the conveyor system and is discharged into the rotary-car dumper pit in which adjustable vibratory feeders place the material on a conveyor belt to be taken directly to a waiting ship or to be placed in stock for later reclamation and shipment. Barge-cleanout service is available through use of a small front-end loader placed in the barge. After residue has been accumulated at one end of the barge, a clamshell is used to complete the clean-up operation. Residue is deposited in hopper bins, which are then unloaded into dump trucks for final deposit in the storage area.

The open storage area has a capacity of 430 000 tons. The electric traveling stacker/reclaimer has a 180-ft boom equipped with a reversible 72-in belt conveyor and a continuous-bucket wheel. It has a stacking rate of 4000 tons/h and a reclaiming rate of 5000 tons/h.

By May 1981, the second phase of development should be complete. This will add a second stacker/reclaimer, two additional storage pads, one more barge unloader, and a rail facility that will accommodate unit trains in a loop track set-up. A total price of $20 million is estimated to complete this work.

Phase 3 of the development will include a new dock, ship loaders, and a third stacker/reclaimer, which will cost approximately $30-35 million. To allow for the second and third phases of development, a 143-acre site was recently acquired by the state immediately adjacent to the existing complex. The new area includes 2800 ft of riverfront berthing space.

According to U.S. Army Corps of Engineers' statistics, the port of Mobile handled 8 million tons of coal and lignite in 1978 [Table 5 (12)]. Of this total, 1.7 million tons were foreign imports, and 2.2 million tons were foreign exports. The remaining tonnage was either for the receipt or the shipment of internal domestic traffic or for local domestic movements. There were no coastwise receipts or shipments. The major sources of supply for this coal are the Coosa, Cahaba Plateau, and Warrier fields in north Alabama; western Kentucky; the Tracy City fields in Tennessee; and small shipments from eastern Kentucky, Illinois, and Indiana.

New Orleans

The port of New Orleans currently handles export coal at two terminals located in Plaquemines Parish. First, Electra-Coal Transfer Corporation, located about 50 miles downstream from New Orleans, is expecting to handle approximately 1.0 million tons of coal for export to Japan this year. Second, the Plaquemines Parish Terminal, operated by International Marine Terminals, Inc. (IMT), is located about 30 miles below New Orleans near Davant. IMT is primarily handling coal for domestic consumption, although the capability exists for export (Figure 5).

The IMT-operated facility first handled coal for export in 1978. It is contemplated that, ultimately, there will be a three-phase facility that can handle 12 million tons/year. The terminal currently accommodates shallow-draft, open-hopper river barges unloaded by a continuous unloader that has a capacity of 5500 tons/h. A 270 000-ton ground storage area is available. Coal is reclaimed by bulldozer at an average rate of 1000 tons/year.

Phase 2 calls for the addition of a new dock and installation of a traveling ship unloader that has an ultimate capacity of 7000 tons/h. In phase 3, a stacker/reclaimer is scheduled to be used at full development and nearly 1 million tons of active storage area will be available. IMT officials have indicated that it is their hope that five or six large-volume customers will require the greatest share of coal.

To accommodate deeper-draft vessels, the U.S. Army Corps of Engineers is reviewing a proposal to

Table 5. Movement of coal and lignite from Mobile Harbor, Alabama.

Year	Total Mobile Harbor Movements	Foreign Imports	Foreign Exports	Domestic Internal Receipts	Domestic Internal Shipments	Domestic Local
1978	7.994	1.745	2.232[a]	2.261	1.751	0.004
1977	8.346	0.866	3.611	3.103	0.765	-
1976	6.797	0.781	2.756	2.541	0.718	-
1975	5.941	0.371	2.745	2.489	0.335	-
1974	3.970	0.143	1.748	2.011	0.070	-

Short Tons (000 000s)

[a]Also shown for Three Mile Creek, Alabama.

Figure 5. Coal export facilities, New Orleans.

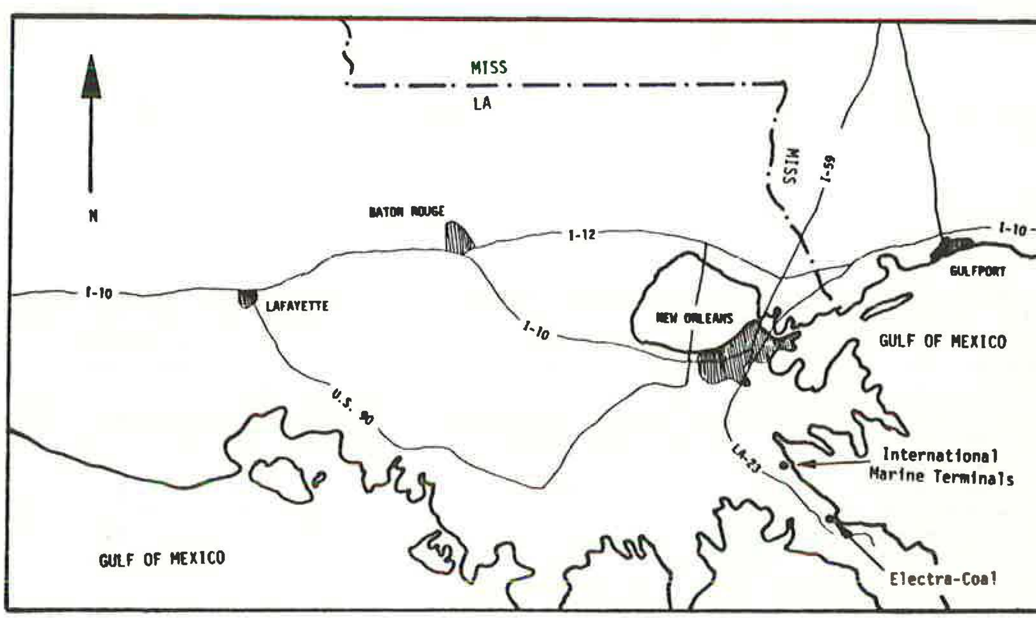


Table 6. Movement of coal and lignite from port of New Orleans.

Year	Total New Orleans Movements	Foreign Imports	Foreign Exports	Domestic Coastwise Receipts	Domestic Coastwise Shipments	Domestic Internal Receipts	Domestic Internal Shipments	Local
1978	7.395	0.027	1.401	0.050	3.145	2.759	0.011	0.002
1977	9.452	0.142	1.438	-	3.587	4.274	0.010	-
1976	8.439	0.195	1.297	-	2.757	4.187	0.003	-
1975	8.711	-	1.236	-	3.096	4.375	0.004	-
1974	8.751	0.002	1.002	-	3.481	4.257	0.008	0.001

Note: Short Tons (000 000s).

deepen the Southwest Pass through New Orleans from 40 ft to 55 ft. Preliminary environmental notifications have been submitted, and if timely congressional approval is obtained, the deepening could be accomplished by 1984.

In 1978, the port of New Orleans handled 7.4 million tons of coal and lignite [Table 6 (12)]. Of this total, 1.4 million tons were for export, 3.1 million tons were as coastwise shipments to other domestic points, and 2.8 million tons were receipts of domestic movements for local consumption.

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Impacts of Proposed Transshipment Facility on Price of Delivered Coal in New York

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Recent federal legislation has been directed toward reducing the use of imported oil, particularly by the utility sector. As a result, numerous oil-fired power plants have been targeted for reconversion to coal. Since transportation costs constitute a major portion of the total delivered-coal price to northeastern utilities, cost savings that might be achieved through efficient transportation methods will enhance the economic practicality of reconversions. The transportation cost savings that would accompany the construction of a large coal storage and transfer facility near the port of New York are estimated here. Total delivered-fuel costs are computed for plants that might reconvert to coal, assuming the use of coal from three supply regions and alternative mode and route configurations. Cost savings that would result from use of the proposed facility are estimated on a plant-specific basis. In addition, projections of annual throughput for a range of transshipment costs are estimated.

Development of intermodal transfer facilities follows logically in the general process of increasing the total efficiency of the national transportation system. Usually constructed at rail-water interfaces, transshipment terminals are designed to reduce the price of delivered bulk commodities.

Government policies currently being formulated will directly affect regional coal markets. The federally mandated program of reconverting oil-fired power plants to coal will increase the demand for coal by utilities in the New York region. Transportation costs will constitute a major portion of the delivered price to these users. Minimization of these costs will enhance the economic feasibility of the coal reconversion program. This paper examines the transportation cost savings that may be realized by New York State utilities through the development of a proposed coal-transfer and storage facility near the port of New York.

Estimates of delivered price from three alternative supply regions, assuming use of several mode and route configurations, are developed and compared to determine the cost savings that would accompany development and use of the proposed facility.

PROSPECT FOR INCREASED COAL USE

Use of coal to supplant imported petroleum products as a fuel for the generation of electricity has been the focus of the recent national energy policy. It has been estimated that coal reserves constitute 80 percent of our fossil-fuel energy reserves (1, pp.

176-180). These supplies can fulfill many of our energy requirements well into the next century. Though it is unreasonable to expect that coal will entirely replace oil, it is probable that an increasing percentage of the generation mix will be made up of coal-fired facilities.

Legislation enacted in the late 1970s has reflected the desire of the federal government to mandate the reconversion of oil- and gas-fired generating stations to coal. This program has met with widely varied opinion within the utility industry. Since the Nixon administration, every president has favored conversion as a major step toward reduction of overall imports of oil. However, conflicting objectives within government agencies have served to limit the effectiveness of these programs to date.

Most recently, the Carter administration sought to provide financial incentives to aid utilities with the capital costs of reconversion. An ambitious reconversion effort has proved difficult for utilities faced with rising fuel costs and an uncertain financial climate.

Though the Reagan administration has indicated a favorable stance toward conversion, financial incentives will most likely not include direct subsidies. In 1981, congressional review of the Clean Air Act of 1970 (P.L. 95-95, 91 Stat. 685) will serve as a bellwether of what may be a massive restructuring of environmental legislation. The decisions reached in this evaluation will, it is hoped, clarify the environmental regulations associated with any program to increase coal use. It seems likely that the 1980s will be an important decade, in which many fundamental questions associated with coal use will be addressed.

LEGISLATIVE ACTIONS AFFECTING COAL USE

Two types of legislation, which often have conflicting goals, have served to create a somewhat ambiguous legal situation. Rising costs of compliance with environmental regulations have added greatly to the overall costs of electricity generation by using coal. Conversely, statutes passed since the oil embargo of 1973-1974 have been designed to encourage the substitution of coal for imported oil and natural gas, particularly for utilities.

Energy Legislation

The Energy Supply and Environmental Coordination Act of 1974 (ESECA) and the Power Plant and Industrial Fuel Use Act of 1978 (PIFUA) represent the major legislative efforts to mandate reconversion to coal. Although it grants the U.S. Department of Energy (DOE) broad powers to prohibit the use of oil or natural gas in utility plants and other major fuel-burning installations, the program has been stymied by a lack of financial incentives and an uncertain regulatory climate.

On June 24, 1980, the Senate passed the Oil and Gas Backout Bill. This legislation contained an appropriation of $4.2 billion to provide utilities with grants and loans for conversion efforts. For the 80 affected generating plants, $3.6 billion was earmarked for mandated conversions, $450 million was available for voluntary conversions, and $150 million was available to aid in development of coal-preparation systems (2). A utility may be eligible to receive up to 25 percent of the capital cost of conversion. If added financial need can be demonstrated, grants for an additional 25 percent or loans of up to 50 percent would be made available. Current indications are that such a subsidy program will not meet with widespread approval (New York Times, Nov. 20, 1980, p. 3).

Environmental Legislation

The significant environmental-related costs of coal combustion are attributable to air-pollution control and disposal of solid wastes generated in the combustion process. A balance must be achieved among these considerations, national goals of reducing dependence on foreign sources of fuel, and economic growth in order to effectively further coal use. The federal government will debate several significant environmental statutes in the 1980s, and the results of these reviews will, in large measure, shape the future for coal use.

The Clean Air Act of 1970 was the initial major legislative effort to significantly affect coal users. The act and subsequent amendments required the U.S. Environmental Protection Agency (EPA) to develop standards for primary and secondary ambient air quality. In December 1971, EPA responded through issuance of the new source performance standards. Utilities could comply with these standards by either (a) direct combustion of low-sulfur coal or (b) use of high-sulfur coal in conjunction with flue-gas desulfurization (FGD) systems.

A revision put forth in 1979 effectively removed the first option as a compliance strategy by requiring emission reduction through the use of so-called best-available control technology (BACT). This policy required that all new coal-fired generating stations--regardless of the sulfur content of coal--install and continuously operate FGD systems.

Previous regulations (Federal Register, June 1, 1978, p. 4; Dec. 18, 1978, p. 5) had established maximum allowable increments for SO_2 pollution in class 1, 2, and 3 areas within the United States. On approval of a state implementation plan (SIP), all regions in compliance with National Ambient Air Quality Standards would be defined as class 2. Areas could then be redesignated 1 or 3 at the discretion of the state and corresponding changes would be made in allowable SO_2 emissions. These regulations further required use of BACT at any new fossil-fuel source that had potential SO_2 emissions of 250 tons/year. Some coal industry representatives have attributed much of the complexity of compliance and evaluation of alternative strategies to these new regulations (3, pp. 117-129).

These new regulations were designed in part to restore competitive balance to the coal industry (4). The market for low-sulfur "compliance" coal had placed a strain on the coal industry in Eastern and Midwestern states that have high-sulfur coal reserves. Whether these regulations will achieve this objective remains open to question. The standards apply to plants constructed after September 18, 1978. FGD systems now remain the only technique that qualifies as BACT under these regulations.

Additional major environmental legislation that affects coal includes the Clean Water Act of 1970 (with subsequent amendments) and the Resource Conservation and Recovery Act of 1976 (RCRA). The latter is designed to improve disposal practices for hazardous waste materials. Classification of utility waste was postponed in recent regulations put forth under this act (Federal Register, June 1, 1978, p. 4; Dec. 18, 1978, p. 5). Determination of the nature of waste materials is based on physical and reactive characteristics of the substance. An alternative strategy, proposed by EPA, to develop a subcategory for "special wastes" could significantly affect costs of compliance for large generators of relatively low-hazard waste. Utility waste materials such as fly ash and scrubber sludge are expected to be included in the proposed classification.

Local environmental regulations will have a significant impact on plans for coal use in the study region. Combustion of coal within New York City is now prohibited by law. The Consolidated Edison Company was granted permission by EPA on August 7, 1980, for a one-year test burn of high-sulfur oil at three generating stations in New York as a prelude to reconversion (New York Times, Aug. 8, 1980, p. 5). Company officials expressed hope that this demonstration would illustrate the practicality of using low-sulfur coal without significant negative impact on the health and welfare of the region. The utility has been using 1.5 percent sulfur oil, approximately equivalent to a 1.0 percent sulfur coal. The decision by EPA to proceed with the test was reached over objections by surrounding states, which reflected a positive attitude toward demonstrating the environmental effects of reconversion.

POTENTIAL CONVERSIONS IN STUDY REGION

Questions related to future generation mix create an uncertain situation for future coal use by utilities that might be served by the proposed facility. In New York, coal use by utilities will remain the greatest percentage share of coal consumption in the state, as it has been historically (5). Potential increases in coal demand are related to the overall growth of electricity demand, any successful programs of voluntary or mandated conversions, and the future development of nuclear-generating capacity.

For this analysis, generating stations in the downstate region cited as candidates for reconversion were used to determine potential demand for coal that could be served by the proposed transshipment facility. Currently, the New York State energy master plan lists 20 generating units at 9 power plants as probable conversions (5). Utilities that have facilities included in this classification are Consolidated Edison (Con Ed) (three plants), Long Island Lighting Company (Lilco) (three plants), Central Hudson Gas and Electric (CHGEC) (one plant), Orange and Rockland (O&R) (one plant), and Niagara Mohawk (one plant). These facilities represent a generating capacity of 5982 MW. With the exception of the Niagara Mohawk plant at Albany, all stations mentioned above are included in the demand analysis; they represent a total generating capacity of 5582 MW. Table 1 (5, p. 174) presents the generating facilities included in this analysis. Completion of these conversions would increase coal consumption by 13.5 x 10^6 tons/year for coal from central Pennsylvania or southern West Virginia and 12.6 x 10^6 tons/year for coal from eastern Kentucky. Supply regions and quality characteristics used in this analysis are outlined in the following section. The plant-specific demand for coal from each supply region is outlined in Table 2. Coal demand for each generating station is computed based on total annual heat requirements to meet generating capacity and applicable heat content for each candidate coal.

COAL-SUPPLY REGIONS

Selection of a coal-supply source is generally based on the user's perception of quality characteristics necessary to achieve generating capacity and to ensure compliance with applicable regulations at a minimum cost. Characteristics such as content of British thermal units and percentage of sulfur content can vary widely from mines within a specific supply region. Such physical characteristics of the coal are determined through formational processes of heat, pressure, depositional history, and groundwater mineral content. As discussed earlier, environmental regulations have, to a large extent, shaped the current utility coal market.

In this analysis, coal-supply regions were selected based on discussions with utility representatives and approximate "typical" supply strategies. Supply nodes utilized here include Clearfield, Pennsylvania, for central Pennsylvania; Beckley, West Virginia, for southern West Virginia; and Thacker, West Virginia, for eastern Kentucky.

Quality characteristics and free-on-board (FOB) mine prices are presented in Table 3 (6). Implicit in selection of the supply sources is the assumption that Eastern coal will remain the minimum-cost alternative over Western coal for the converted plants. Transportation alternatives evaluated correspond to logical patterns of transportation from supply regions noted.

TRANSPORTATION ALTERNATIVES

Utility officials have stressed the importance of evaluating alternative strategies both for supply and for transportation to avoid the development of a "captive" market for Eastern coal movements. Five mode and route configurations were compared in this analysis (EGS stands for electric-generating station; NYCCHF stands for New York City coal-handling facility):

For central Pennsylvania coal:

ALLRAIL

RAILBARGE 1: rail to Philadelphia, barge to EGS

RAILBARGE 4: rail to Port Reading, NJ; barge to EGS

Table 1. Power plants for probable conversion to coal.

Electric-Generating Station	Operating Company	Conversion Service Date	Capacity (MW)
Arthurkill (nos. 2 and 3)	Con Ed	1984	851
Ravenswood (no. 3)	Con Ed	1984	928
Port Jefferson (nos. 3 and 4)	Lilco	1984	380
E. F. Barrett (nos. 1 and 2)	Lilco	1988	380
Northport (nos. 1 to 4)	Lilco	1989	1532
Danskammer (nos. 3 and 4)	CHGEC	1982	342
Lovett (nos. 4 and 5)	O&R	1986	399
Ravenswood (nos. 1 and 2)	Con Ed	1987	770

Table 2. Coal demand potential from supply region.

	Supply Region		
Electric-Generating Station	Central Pennsylvania	Southern West Virginia	Eastern Kentucky
Arthurkill (nos. 2 and 3)	2 093 684	2 093 684	2 013 158
Ravenswood (no. 3)	2 277 629	2 277 629	2 190 028
Port Jefferson (nos. 3 and 4)	883 577	883 577	849 593
E. F. Barrett (nos. 1 and 2)	954 287	954 287	917 584
Northport (nos. 1 to 4)	3 558 371	3 558 371	3 421 510
Danskammer (nos. 3 and 4)	824 585	824 585	792 870
Lovett (nos. 4 and 5)	1 017 541	1 017 541	978 405
Ravenswood (nos. 1 and 2)	1 881 600	1 881 600	1 809 231
Total	13 491 274	13 491 274	12 672 379

Table 3. Coal-quality characteristics and FOB mine prices.

Supply Region	Heat Content (Btu/lb)	Sulfur Content (% by wt)	FOB Mine Price ($) Term	FOB Mine Price ($) Spot
Central Pennsylvania	12 500	1.0	31.00	29.00
Southern West Virginia	12 500	1.5	29.50	26.00
Eastern Kentucky	13 000	0.7	37.00	33.00

RAILBARGE 5: Rail to NYCCHF, barge to EGS

For southern West Virginia coal:

ALLRAIL
RAILBARGE 2: rail to Norfolk, barge to EGS
RAILBARGE 4: rail to Port Reading, NJ; barge to EGS
RAILBARGE 3: rail to Newport News, barge to EGS
RAILBARGE 5: rail to NYCCHF, barge to EGS

For eastern Kentucky coal:

ALLRAIL
RAILBARGE 2: rail to Norfolk, barge to EGS
RAILBARGE 4: rail to Port Reading, NJ; barge to EGS
RAILBARGE 5: rail to NYCCHF, barge to EGS

Lengths of haul from each supply region to generating stations were obtained from state transportation maps of New York, New Jersey, Pennsylvania, Virginia, and West Virginia. Tidewater distances were obtained from the U.S. Coast and Geodetic Survey (7).

Unless otherwise noted, all estimates of unit-train rates used in this analysis were derived from a regression model that expresses rates in dollars per ton as a linear function of the length of haul. Single-car rates were computed in a similar manner. Data regarding existing rate structures between supply regions and tidewater ports were obtained through discussions with personnel of the Consolidated Rail Corporation (Conrail), the Chessie System, and the Norfolk and Western Railway Company.

Unit-train rates apply for shipments in excess of 7000 tons for one origin. Calibration of quoted rail rates to length of haul yielded the following relationships:

For unit-train rates:

$$U = 6.65 + 0.015X \quad R^2 = 0.89 \tag{1}$$

where

U = unit-train rate ($/ton),
X = rail-line distance between supply region and generating facility, and
R^2 = proportion of variation in quoted rate accounted for by length of haul.

For single-car rates:

$$S = 9.97 + 0.017X \quad R^2 = 0.67 \tag{2}$$

where S is the single-car rate in dollars per ton and X and R^2 are as in Equation 1.

In evaluating RAILBARGE alternatives, transshipment costs are assumed to be included in the rail rate. This was found to be the standard practice of railroads that retain ownership of coal-transfer facilities at tidewater ports. For the proposed transshipment terminal, varying levels of costs were evaluated. This sensitivity analysis yields insight into the cost levels necessary to achieve positive benefits for users.

Costs for waterborne movements are based on similar intercoastal shipments to a recently converted power plant in Massachusetts. These costs are recognized to be highly variable and based on factors such as vessel size, ownership, and the length of haul. Vessel sizes range from 2400-ton coastal barges to large ocean-going colliers in the 20 000-ton range. Comparative ton-mile transportation costs are shown below:

Mode	Cost ($/ton mile)
Rail	0.02-0.03
Barge	0.01-0.02

ANALYTICAL STRUCTURE

Delivered-coal prices were developed for each supply region and applicable transportation configuration. Estimates are based on FOB mine prices (Table 3) and modal rate estimates for each movement. The least-cost alternative for each generating facility is given in Table 4. Delivered-price estimates developed for RAILBARGE alternative 5 were, as discussed earlier, developed for various levels of per-ton transshipment cost. These estimates are fully explained in Table 5 and are compared directly with the least-cost alternative to determine transportation cost savings. Evaluation of these estimates based on plant-specific coal demand yields total benefits, shown in Table 6. The structure of the analytical methodology that was used is shown below:

1. FOB mine prices for three types of coal: central Pennsylvania, southern West Virginia, and eastern Kentucky;
2. Transportation costs:
   a. For four route options for central Pennsylvania coal: ALLRAIL, RAILBARGE 1, RAILBARGE 4, and RAILBARGE 5;
   b. For five route options for southern West Virginia coal: ALLRAIL, RAILBARGE 2, RAILBARGE 3, RAILBARGE 4, and RAILBARGE 5;
   c. For four route options for eastern Kentucky coal: ALLRAIL, RAILBARGE 2, RAILBARGE 4, and RAILBARGE 5;
3. Least-cost alternative for three types of coal;
4. Comparison with RAILBARGE 5; and
5. Evaluation of benefits.

EVALUATION

In terms of total benefits (per-ton transportation cost savings on a plant-specific basis multiplied by the demand potential of that plant), it would appear that ALLRAIL remains the minimum-cost alternative for plants at which rail infrastructure exists. Rail service extends to four plants used in this analysis: Lovett, Danskammer, Arthurkill, and E.F. Barrett. It is unreasonable, we believe, to assume that rail service will be extended to additional facilities due to attendant high construction costs and impacts on existing land use patterns.

Coal shipments bound for the E.F. Barrett station must be routed via Poughkeepsie or in some cases even further up the Hudson Valley. This excessive rail mileage militates against the ALLRAIL alternative for this facility.

At lower transshipment costs, use of the facility yields benefits in comparison with other RAILBARGE alternatives. For movements of central Pennsylvania coal, the proposed facility remains competitive at transshipment costs of $2.00/ton. For southern West Virginia coal, the facility yields benefits up to cost levels of $1.50/ton. Movements of more-expensive low-sulfur eastern Kentucky coal would not achieve savings at cost levels greater than $1.00/ton.

It is important to note that these benefits are low-end estimates. No provision is made for savings to users for additional storage capacity or savings in on-site coal-handling systems related to the facility. Table 7 lists the total annual benefits attributable to the proposed facility in terms of aggregate transportation cost savings. Estimates of annual throughput also vary with cost for transshipment. At $1.00/ton, throughput ranges from 9.6 million tons of central Pennsylvania or southern West Virginia coal to 4.4 million tons from eastern Kentucky. Cost levels of $2.00/ton result in a decrease in throughput to 8.6 million tons from central Pennsylvania and 4.4 million tons from southern West Virginia. (These throughput estimates assume that all plants will use the same coal supply source.)

The large backlog of loadings at the port of Norfolk adds greatly to the cost of transporting coal from that region. In developing an alternative scenario we have assumed that such congestion creates an unacceptable or overly costly service for utilities that results in an altered transportation strategy. To evaluate the effects of this situation, it was assumed that shipment via Norfolk was infeasible. Transportation cost savings were computed as in the base case.

Total benefits for this scenario are presented in Table 8. For the E.F. Barrett power plant, the use of the facility would yield benefits to transshipment cost levels of \$1.50/ton compared with ALLRAIL. Generating stations not served by ALLRAIL are assumed to use RAILBARGE 4 (Port Reading, New Jersey). In general, use of the facility would yield savings throughout the range of cost levels for all three supply regions. Annual benefits for this alternative scenario are presented in Table 9.

For the alternative scenario, a throughput of 9.6 million tons of central Pennsylvania or southern West Virginia coal could be realized for transshipment costs as high as \$4.00/ton. For eastern Kentucky coal, throughput is estimated to be 9.2 million tons/year at a similar cost level.

Table 4. Least-cost delivered-price alternatives.

Supply Region	Electric-Generating Station	Least-Cost Alternative	Delivered-Price Estimate (\$)
Central Pennsylvania	Lovett	ALLRAIL	43.25
	Danskammer	ALLRAIL	43.52
	Arthurkill	ALLRAIL	42.53
	E. F. Barrett	RAILBARGE 1[a]	44.69
	Ravenswood	RAILBARGE 1	44.84
	Northport	RAILBARGE 1	45.63
	Port Jefferson	RAILBARGE 1	45.83
Southern West Virginia	Lovett	ALLRAIL	45.78
	Danskammer	ALLRAIL	46.05
	Arthurkill	ALLRAIL	45.06
	E. F. Barrett	RAILBARGE 2[a]	46.88
	Ravenswood	RAILBARGE 2	47.01
	Northport	RAILBARGE 2	47.70
	Port Jefferson	RAILBARGE 2	47.88
Eastern Kentucky	Lovett	ALLRAIL	54.45
	Danskammer	ALLRAIL	54.72
	Arthurkill	ALLRAIL	53.73
	E. F. Barrett	RAILBARGE 2[a]	54.59
	Ravenswood	RAILBARGE 2	54.72
	Northport	RAILBARGE 2	55.41
	Port Jefferson	RAILBARGE 2	55.59

[a]Assumes presence of transfer facilities at plant.

CONSIDERATIONS IN SITE SELECTION

From the standpoint of practical planning, criteria for evaluating potential locations of intermodal transshipment facilities are relatively straightforward. Successful operation is dependent on the adequacy of rail service and access to adequate shipping channels. The unique harbor environment of the study region presents a somewhat more difficult situation for planners of the proposed facility. Discussions with the planning staff of the Port Authority of New York and New Jersey have indicated that the preferred site is located on the east bank of the Hudson River in the area between the Lincoln Tunnel and the Verrazano Narrows Bridge. This general location would make use of the existing rail system to minimize new track construction and would minimize necessary dredging.

For the general purpose of analyzing the economic impacts of the proposed facility, a site on the eastern shore of Staten Island was selected. The facility is assumed to be of sufficient size to handle the demand requirements of the reconversions examined in this analysis. Decisions regarding the exact nature of the proposed transshipment facility have not been firmly established. We have assumed a facility of size and configuration competitive with similar facilities on the East Coast.

Larger, more modern facilities such as the Superior Midwest Energy Terminal were designed for maximum efficiency and minimum environmental impact. It is expected that similar considerations will be paramount in the development of the proposed transshipment terminal in New York. To facilitate rapid turnaround, a loop track is preferred so that unit trains can be unloaded with little or no switching.

CONCLUSIONS

The current level of governmental interest in increased coal use will have significant impacts on

Table 5. Transshipment cost sensitivity.

		Delivered-Price Estimate (\$)						
		Transshipment Cost (\$/ton)						
Supply Region	Electric-Generating Station	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Central Pennsylvania	Lovett	43.98	44.48	44.98	45.48	45.98	46.48	46.98
	Danskammer	44.18	44.68	45.18	45.68	46.18	46.68	47.18
	Arthurkill	43.79	44.29	44.79	45.29	45.79	46.29	46.79
	E. F. Barrett	43.87	44.37	44.87	45.37	45.87	46.37	46.87
	Ravenswood	43.67	44.17	44.67	45.17	45.67	46.17	46.67
	Northport	44.00	44.50	45.00	45.50	46.00	46.50	47.00
	Port Jefferson	44.12	44.62	45.12	45.62	46.12	46.62	47.12
Southern West Virginia	Lovett	46.52	47.02	47.52	48.02	48.52	49.02	49.52
	Danskammer	46.72	47.22	47.72	48.22	48.72	49.22	49.72
	Arthurkill	45.33	46.83	47.33	47.83	48.33	48.83	49.33
	E. F. Barrett	46.41	46.91	47.41	47.91	48.41	48.91	49.41
	Ravenswood	46.54	47.04	47.54	48.04	48.54	49.04	49.54
	Northport	46.54	47.04	47.54	48.04	48.54	49.04	49.54
	Port Jefferson	46.66	47.16	47.66	48.16	48.66	49.16	49.66
Eastern Kentucky	Lovett	55.19	55.69	56.19	56.69	57.19	57.69	58.19
	Danskammer	55.39	55.89	56.39	56.89	57.39	57.89	58.39
	Arthurkill	55.00	55.50	56.00	56.50	57.00	57.50	58.00
	E. F. Barrett	55.08	55.58	56.08	56.58	57.08	57.58	58.08
	Ravenswood	54.88	55.38	55.88	56.38	56.88	57.38	57.88
	Northport	55.21	55.71	56.21	56.71	57.21	57.71	58.21
	Port Jefferson	55.33	55.83	56.33	56.83	57.33	57.83	58.33

Table 6. Total benefits.

Electric-Generating Station	Least-Cost Alternative	Supply Region	Benefits ($000 000s) Transshipment Cost ($/ton) 1.0	1.5	2.0	2.5	3.0	3.5	4.0
Lovett	ALLRAIL	CPA	-0.74	-1.3	-1.8	-2.3	-2.8	-3.3	-3.8
		SWVA	-0.75	-1.3	-1.8	-2.3	-2.8	-3.3	-3.8
		EKY	-0.72	-1.2	-1.7	-2.2	-2.7	-3.2	-3.7
Danskammer	ALLRAIL	CPA	-0.54	-0.96	-1.4	-1.8	-2.2	-2.6	-3.0
		SWVA	-0.55	-0.97	-1.4	-1.8	-2.2	-2.6	-3.0
		EKY	-0.53	-0.93	-1.3	-1.8	-2.1	-2.5	-2.9
Arthurkill	ALLRAIL	CPA	-2.6	-3.7	-4.7	-5.8	-6.8	-7.9	-8.9
		SWVA	-2.7	-3.7	-4.8	-5.8	-6.8	-7.9	-8.9
		EKY	-2.6	-3.6	-4.7	-5.6	-6.6	-7.6	-8.6
E. F. Barrett	RAILBARGE 1	CPA	0.78	0.31	-0.17	-0.65	-1.1	-1.6	-2.1
	RAILBARGE 2	SWVA	0.45	-0.00	-0.50	-0.98	-1.5	-1.9	-2.4
	RAILBARGE 2	EKY	-0.45	-0.91	-1.4	-1.8	-2.3	-2.7	-3.2
Ravenswood	RAILBARGE 1	CPA	4.9	2.8	0.71	-1.4	-3.4	-5.5	-7.6
	RAILBARGE 2	SWVA	3.3	1.3	-0.83	-4.2	-5.0	-7.0	-9.1
	RAILBARGE 2	EKY	-0.64	-2.6	-4.6	-6.6	-8.6	-10.6	-12.5
Northport	RAILBARGE 1	CPA	5.8	4.0	2.2	0.46	-1.3	-3.1	-4.9
	RAILBARGE 2	SWVA	4.1	2.4	0.57	-1.2	-3.0	-4.8	-6.6
	RAILBARGE 2	EKY	0.68	-1.0	-2.7	-4.5	-6.2	-7.9	-9.6
Port Jefferson	RAILBARGE 1	CPA	1.5	1.1	0.63	0.19	-0.26	0.70	-1.1
	RAILBARGE 2	SWVA	1.1	0.64	0.19	-0.28	-0.69	-1.1	-1.6
	RAILBARGE 2	EKY	0.22	-2.0	-0.63	-1.1	-1.5	-1.9	-2.3

Note: Supply regions abbreviated as follows: Central Pennsylvania, CPA; southern West Virginia, SWVA; eastern Kentucky, EKY.

Table 7. Total annual benefits, base case.

Transshipment Cost ($/ton)	Throughput by Supply Region (tons 000 000s) CPA	SWVA	EKY	Benefits ($000 000s) CPA	SWVA	EKY
1.0	12.98	8.95	0.90	9.6	9.6	4.4
1.5	8.21	4.34	0.00	9.6	8.6	-
2.0	3.54	0.76	0.00	8.6	4.4	-
2.5	0.65	0.00	0.00	4.4	-	-
3.0	0.00	0.00	0.00	-	-	-
3.5	0.00	0.00	0.00	-	-	-
4.0	0.00	0.00	0.00	-	-	-

Table 8. Total benefits, scenario 1.

Electric-Generating Station	Second Least-Cost Alternative	Supply Region	Benefits ($000 000s) Transshipment Cost ($/ton) 1.0	1.5	2.0	2.5	3.0	3.5	4.0
E. F. Barrett	ALLRAIL	PA	0.95	0.47	0.00	-0.47	-0.95	-1.4	-1.9
		SWVA	0.94	0.47	-0.01	-0.47	-0.96	-1.4	-1.9
		EKY	0.91	0.45	-0.01	-0.47	-0.92	-1.4	-1.8
Ravenswood	RAILBARGE 4	CPA	10.7	8.6	6.6	4.5	2.4	0.33	-1.8
		SWVA	12.8	10.8	8.7	6.7	4.6	2.5	0.42
		EKY	12.4	10.4	8.4	6.4	4.4	2.4	0.40
Northport	RAILBARGE 4	CPA	9.2	7.4	5.6	3.8	2.1	0.28	-1.4
		SWVA	11.0	9.3	7.5	5.7	3.9	2.1	0.36
		EKY	10.6	8.9	7.2	5.5	3.7	2.1	0.34
Port Jefferson	RAILBARGE 4	CPA	2.3	1.8	1.4	0.95	0.51	0.01	-0.37
		SWVA	2.7	2.3	1.9	1.4	0.97	0.53	0.01
		EKY	2.6	2.2	1.8	1.4	0.93	0.51	0.01

the market for coal and the transportation system that it will traverse. Increased use will certainly contribute to delays and congestion similar to those already being experienced at Norfolk. It is apparent that these problems decrease the overall efficiency of the transport network, which adds greatly to transportation costs. The development of a proposed transshipment facility in New York may serve to relieve some congestion at other ports through direct competition with similar facilities that yield only marginal economic benefits. Further expansion of coal traffic may tax existing terminals to the point of diminishing returns in cost savings, thus enhancing economic feasibility of the proposed facility.

If transshipment cost levels examined in this analysis could be maintained, developers of the proposed facility could expect a throughput of up to 10 million tons/year. This estimate reflects only part of the potential demand. Further evaluation is necessary to determine the nature of the facility and the potential to serve roles different from those evaluated here.

ACKNOWLEDGMENT

We would like to acknowledge officials at various

Table 9. Annual benefits, scenario 1.

Transshipment Cost ($/ton)	Throughput by Supply Region (tons 000 000s)			Benefits ($000 000s)		
	CPA	SWVA	EKY	CPA	SWVA	EKY
1.0	23.50	27.44	26.51	9.6	9.6	9.2
1.5	18.27	22.87	21.95	9.6	9.6	9.2
2.0	13.60	18.10	17.42	9.6	9.6	9.2
2.5	9.25	13.80	13.30	9.6	9.6	9.2
3.0	5.01	9.47	9.03	9.6	9.6	9.2
3.5	0.62	5.13	5.01	9.6	9.6	9.2
4.0	0.00	0.79	0.75		9.6	9.2

northeastern utilities for providing valuable insight regarding the industry viewpoint on issues discussed here. We are also grateful to the personnel of coal bureaus of the various railroads used in this analysis for providing necessary rate information and to the planning staff of the Port Authority of New York and New Jersey for added useful information. Finally, we would like to thank our typist, Alice Frolo.

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Physical and Operating Characteristics of Ferry Vessels

ARNOLD J. BLOCH

The state of the art of ferry-vessel technology, including conventional slow-speed ships and high-speed ships, is discussed. The latter models, although used regularly in Europe and Canada, have had limited operating experience in the United States. Important vessel features are highlighted, including passenger and vehicle capacity, engine and propulsion systems, hull design, speed and steering control, docking procedures, and passenger amenities. Conventional low-speed diesel-powered vessels consume less energy than their high-speed gasoline turbine counterparts. On the other hand, high-speed vessels offer service-quality capabilities that are highly competitive with automobile commutation. However, there has been little opportunity to demonstrate the advantages of high-speed vessels, mainly because of legislative restrictions.

Ferry systems operate within diverse environments and serve different types and levels of passenger, vehicle, and even freight demands. Consequently, there is a wide range of vessel types now in operation. However, one generalization can safely be made concerning vessels currently in operation in the United States and Canada: Most rely on long-established and conventional sources of power and propulsion and as such are not high-speed ships. That is, most cannot achieve a speed greater than 20 knots (23 mph). Despite the existence of hydrofoils, hovercraft, and surface-effect ships, which can achieve speeds greater than 40 knots (46 mph), use of these high-speed craft is confined to service in Europe and the Far East, as well as to American military programs. In fact, the Golden Gate Ferry in San Francisco is the only system in this country that relies on relatively high-speed vessels, and they achieve a cruising speed of only 25 knots (29 mph).

There are a number of reasons that American ferry systems do not use high-speed craft, some of which are listed below:

1. Many ferry-route distances are relatively short;
2. Longer ferry routes normally serve vehicle as well as pedestrian demand, which requires larger ship dimensions than most high-speed craft now offer;
3. Many ferries operate in heavily used waterways, often against the normal stream of ship traffic, which mandates lower operating speeds; and
4. Many high-speed craft (especially hovercraft) are foreign-built and thus prohibited from U.S. service by the Merchant Marine Act of 1920 (Jones Act).

However, a number of factors make it likely that high-speed vessels may see future domestic service. First, U.S. manufacturers have built and operated both hydrofoil and surface-effect ship prototypes, some of which are in operation elsewhere in the world. Second, planning objectives in urban areas may evolve, as they have already in San Francisco, from using ferries as bridge substitutes between key highway, transit, or pedestrian links into using high-speed craft to provide a competitive alternative commuter mode to the automobile between the central city and outlying areas. For such a plan to be feasible, the ferry would have to duplicate a number of automobile characteristics, among them speed (i.e., travel time). Third, the pedestrian-only feature of most high-speed craft fits in well with both urban (and recreational) area goals of reduction in automobile use, especially during peak-demand hours.

This paper presents a state-of-the-art exposition of ferry vessels available for current use. It discusses both conventional (slow-speed) vessels, which are widely used in this country, as well as high-speed ships, which, although their deployment is limited in the United States, represent products of available and fully tested technology. The objective of this paper is to provide a compendium of vessel information for the urban transportation planner who has little information and virtually no systematic procedure for considering the waterborne alternative for passenger transportation.

Important features of ferry vessels are highlighted in this effort, specifically, vessel functions, engine types and propulsion systems, hull design, vessel-control mechanisms, docking procedures, and passenger amenities. Tables 1 and 2 may be consulted for a summary of key physical and operating characteristics of selected slow- and high-speed vessels.

VESSEL FUNCTIONS: PASSENGER-VEHICLE MIX

Slow-Speed Ships

Slow-speed vessels can carry pedestrians only (normally carry-on bicycles are allowed, too), pedestrians and passenger cars, or pedestrians and a combination of vehicle types that includes passenger cars, recreational vehicles, small trucks, tractor-trailers, and buses. Vehicular and pedestrian capacity vary widely, but some notable examples are mentioned below:

1. The largest pedestrian-only ferries will operate soon for the Staten Island Ferry in New York City. These vessels, now being built, will be more than 300 ft long and will carry about 6000 seated and standing passengers.
2. Ferry vessels that are larger but have less passenger capacity operate in limited settings. They are between 300 and 450 ft long and carry between 1500 and 2500 passengers and between 160 and 460 automobiles.
3. Typically, most vessels between 200 and 300 ft in length carry no more than 100 automobiles and 1000+ passengers; the existing Staten Island Ferry vessels are the major exception (i.e., they are nearly 300 ft long and their automobile capacity is less than 60 but their passenger capacity exceeds 3500).
4. Many small vessels (around 100 ft long) operate in mainland-to-island services throughout the United States and Canada. They normally carry less than 200 passengers and fewer than 30 automobiles. The Vancouver SEABUS, however, is a very efficient small ferry vessel. Shown in Figure 1, it is only 112 ft long but carries 400 persons (but no vehicles).

High-Speed Ships

Those high-speed ships in domestic operation or running on a test basis in the United States are vessels for pedestrians only. In San Francisco, relatively small vessels (165 ft long, less than 100 gross tons) can hold an unusually high number of passengers (750) because of minimum engine size and slight hull submergence and despite the use of oversized airplane-type seating. On the other hand, the Boeing Jetfoil, a fully submerged hydrofoil that cruises at 43 knots (50 mph) seats only about 240-260. Similarly, the other American-made high-speed craft, the Bell-Halter surface-effect ship, which cruises at 40 knots (46 mph) in calm waters and is only 110 ft long, has a capacity of approximately 240.

Hovercraft, also known as air-cushion vehicles, operate across the English Channel at capacities of between 90 and 250 persons, and some hold as many as 60 subcompact automobiles. The Bell Aerospace Canada AL-30 has been designed to hold 200 passengers (but no vehicles) while it cruises at 41 knots (47 mph).

ENGINE TYPES AND PROPULSION SYSTEMS

Slow-Speed Ships

Virtually all slow-speed vessels are diesel-powered, since they provide for adequate operating speeds while consuming less fuel than the gas-turbine-engine alternatives. In addition, diesel fuel has traditionally been a cheaper fuel than the jet fuel used in gas turbines, because fewer refining steps are required.

Diesel engine power is normally converted into forward thrust by marine propellers mounted below the water surface to a shaft driven by the engine or engines. Although the prime objective of marine propellers is to produce vessel thrust, they can also be used to increase overall maneuverability. Added vessel guidance is important in order to avoid the busy ship traffic found in urban harbors that often cuts across ferry routes. There is also a large amount of debris to be avoided in these urban harbors. But the main advantage is during docking, especially on quick-turnaround routes in which this procedure must be handled quickly and smoothly with minimum damage to the ship or the dock. The problem is that, during docking, the vessel is operating at a very low speed and thus fine directional changes by using a rudder in conjunction with propeller thrust are nearly impossible to make. As a result, some vessels (e.g., the Staten Island Ferry) literally have to crash into the dock's retaining walls in order to straighten themselves for final docking, which causes significant damage over time.

Three propeller systems have been used to provide the added maneuverability. All are similar in that the positioning of the propeller blades can be altered from their typical fixed mounting onto the drive shaft. This allows engine thrust to be redirected quickly and can be accomplished at very low speeds, whereas shifting the rudder gives only marginal response at low speeds. These three propeller systems are as follows:

1. Controllable- (or variable-) pitch propeller: This propeller resembles a conventional screw propeller, except that the angle (or pitch) of the blades can be altered during operation from the pilot house.
2. Rotating propellers: As used on the Vancouver SEABUS, the shaft to which a conventional screw propeller is mounted can be rotated 360° around its axis. Positioning four such propellers on the corners of the boxlike SEABUS vessel allows the pilot to maneuver the ship into a docking area that has only a 1-in lateral clearance on each side.
3. Cycloidal propeller: The ultimate in maneuverability, as well as in capital and operating expense, the cycloidal propeller is unlike traditional screw propellers. Blades are attached to the perimeter of a disk that faces downward, and the disk then rotates around a shaft. The blades can be shifted in any direction, which allows propeller thrust to be varied uniformly and sensitively in any direction. New Staten Island Ferry vessels will be equipped with these propellers; this will be their first appearance on domestic ferry ships. As with the rotating propellers in the Vancouver SEABUS, their use eliminates the need for a rudder and steering gear.

High-Speed Ships

In contrast to their slow-speed counterparts, virtually all high-speed ships are powered by gas-turbine engines. (The surface-effect ship is the one exception, to be discussed later.) These engines are lighter and more compact than diesels, a key factor for the smaller high-speed vessels. In San Francisco, for instance, the decision whether to use gas turbines or diesels for high-speed performance of relatively small ships (less than 100 gross tons) proved to be simple. In order to provide the equivalent 8400 total hp necessary to achieve a 25-knot cruising speed, high-performance diesel engines that weigh more than 40 times more and occupy five times more space than gas-turbine engines would have had to been used. This would have drastically reduced seating capacity.

On the other hand, gas turbines consume fuel at a greater rate than diesels, and the cost of the fuel

Table 1. Physical and operating characteristics of selected conventional (slow-speed) ferry vessels.

Vessel and System	Vessel Length	Passenger Capacity	Vehicles (no. automobile-equivalent)	Engine Type	Propulsion System	Maximum Speed (knots)	Hull Type	Docking and Loading Procedures	Crew Size	Vessel Cost[a] ($000 000s)
Large vessels										
Staten Island Ferry; New York City; under construction	310 ft	5748[b]	0	Diesel	Cycloidal propeller (two)	18.5	Steel displacement hull	Double-ended berthing and passenger loading	13	16
Washington State Ferry; Superferries, Seattle, Washington; built 1967	382 ft 2 in	2500	160	Diesel	Fixed propeller (one fore and one aft)	18	Steel displacement hull	Double-ended berthing and vehicle/passenger loading	19	6
Mid-sized vessels										
Cape May-Lewes Ferry; Cape May, New Jersey; built 1974	310 ft	800	100	Diesel	Fixed propeller (twin-screw)	15-16	Steel displacement hull	Single-ended berthing but double-ended vehicle/passenger loading	9	3.9
M/V le Conte, Alaska Marine Highway; Juneau, Alaska; built 1974	235 ft 9 in	250	47	Diesel	Fixed propeller (twin-screw)	16.5	Steel displacement hull	Single-ended berthing; vehicles load via stern door or side doors	24	5.5
Small vessels										
Vancouver SEABUS; Vancouver, British Columbia, Canada; built 1977	112 ft 6 in	400	0	Diesel	Rotating propellers (twin-screw, one fore and one aft)	15	Aluminum catamaran	Double-ended berthing; passengers load from sides	4	4
Robert Noble, Washington Island Ferry Line; Washington Island, Wisconsin; built 1979	90 ft	175	18	Diesel	Fixed propeller (twin-screw)	9	Steel, flat-bottom hull	Single-ended berthing but double-ended vehicle/passenger loading	2	0.7

Note: 1 knot = 1.15 mph.
[a]At year of completion. [b]Of which 3721 may be seated.

Table 2. Physical and operating characteristics of selected high-speed ferry vessels.

Vessel and System or Manufacturer	Vessel Length	Passenger Capacity	Engine Type	Propulsion System	Additional Lifting System	Maximum Speed (knots)	Fuel Consumption at Full Speed: Gallons per Hour	Fuel Consumption at Full Speed: Gallons per Passenger Hour[a]	Hull Type	Docking and Loading Procedures	Crew Size	Vessel Cost[b] ($000 000s)
Golden Gate Ferry; San Francisco, California; built in 1978	164 ft 4 in	750	Gas turbine	Waterjet propulsion (one unit/engine)	None	30	642	0.85	Aluminum, semiplaning	Single-ended berthing; side loading of passengers via gangways	10	8
Boeing Jetfoil; hydrofoil vessel built by Boeing Corp., Seattle, Washington, in 1977; operated on test basis by Washington State Ferry, currently operated on English Channel	90 ft	242-420	Gas turbine	Waterjet propulsion	Fully retractable foils	43+	540	2.23-1.29	Aluminum, semiplaning; rides either hullborne or on single front foil and double rear foil	Berths as conventional hullborne vessel; side loading of passengers via gangways	4-6	10.5
Bell-Halter surface-effect ship; built by Bell Aerospace Textron and Halter Marine, Inc., New Orleans, Louisiana, in 1978; operated on test runs only	110 ft	240	Diesel	Fixed propellers (twin-screw)	Fans mounted below deck create air cushion between side walls and flexible fore and aft seals	40+	176	0.73	Aluminum box-shaped hull resting on catamaran side walls; elastomer seals fore and aft	Berths as conventional hullborne vessel; side loading of passengers via gangways	4	6
Air-cushion vehicle (hovercraft); AL-30 model built by Bell Aerospace Canada, in 1970s	76 ft 3 in	200	Gas turbine	Variable-pitch propellers	Two fans mounted on deck create air cushion within flexible seal around hull perimeter	56	262	1.31	Aluminum flatbed hull with elastomer seal completely surrounding perimeter	Berths on land-based ramp; passengers loading via ramps	2	≈10

Note: 1 knot = 1.15 mph.
[a]At full capacity. [b]At year of completion.

Figure 1. Vancouver SEABUS (two views).

(jet fuel or even light diesel) is greater than that of the middle distillates used by diesel engines. The Golden Gate Ferry vessel, the Jetfoil, and the air-cushion vehicle consume more fuel per hour than the surface-effect ship does, the only one powered by diesel engines. On a per-passenger basis, however, the high passenger capacity of the Golden Gate Ferry vessel makes it nearly the equal of the surface-effect ship.

Propulsion is provided in more varied ways than among slow-speed vessels. Marine propellers are one option, although high speeds require specially designed blades that resist speed deterioration normally caused by quickly agitating water.

Another option is waterjet propulsion, in which water is drawn into the ship's bottom and then thrust out at the stern by means of a pump. Waterjets have a number of advantages over marine propellers: They are quieter; their machinery is simpler and situated within the hull, thus reducing damage due to debris; their discharge can be used as a movable rudder, which increases maneuverability; and their use enables ships to have a shallow draft. This last feature is important in that it can reduce the amount of dredging necessary to accommodate ferry vessels, an important consideration in San Francisco's decision to use waterjet propulsion for its high-speed vessels. On the other hand, waterjets are less efficient in providing thrust than marine propellers, especially at low speeds. Furthermore, due to ducting, a considerable amount of volume is lost within the ship.

A third option is air propulsion, which can be used in either of two ways. On fully amphibious hovercraft (also called air-cushion vehicles), fans mounted to the deck propel the ship over sea and onto land-based docks. Surface-effect ships (known as hovermarines in Europe) also use air propulsion but only when operating at high speeds. They can operate as conventional hullborne vessels powered by diesel engines that have thrust delivered by conventional fixed-pitch marine propellers. As such, these vessels are actually slow-speed ships that achieve a maximum speed of only 19 knots in calm waters. However, an air pocket can be created under the ship's hull, which causes a lifting, friction-cutting effect and allows the ship to achieve speeds of between 40 and 50 knots. The air cushion is produced by fans located below the hull that are powered by two additional diesel engines. Surface-effect ships are the only high-speed vessels that use diesel engines, although gas turbines are optional.

HULL DESIGN

Slow-Speed Ships

Most operating ferry vessels have a conventionally designed displacement hull, normally manufactured from steel. This design is both well proved and inexpensive. The disadvantages of this hull design are its inherent poor stability (which results in passenger discomfort when the vessel is operating in choppy waters) and the large draft that it produces. An alternative hull design employs aluminum catamarans, or dual hulls that consist of two pontoonlike structures separated by a spanning deck. The best currently operating example of this hull design is the Vancouver SEABUS (Figure 1). This design has inherent small displacement and draft and offers good stability for passengers. It also allows for a wider deck (and therefore greater passenger capacity) to be used on relatively narrow supports than could be used on a single-hull design.

High-Speed Ships

Each high-speed vessel type has a hull design that sets it apart as essentially a unique ship design.

Planing Ships

Planing ships are so named because the wedge-shaped hull design minimizes resistance and actually lifts itself partly out of the water (which is known as planing) during high-speed operation. The Golden Gate Ferry uses semiplaning vessels, in which only the bow of the ship is wedge-shaped and the stern is squared off. This affords passengers a more comfortable ride, since the ride quality of a fully planed ship at high speeds is poor.

Hydrofoil

The hydrofoil is a planing-hull vessel supported by vertical foils, so that the hull rides completely above the surface of the water and provides no resistance to high-speed (40-knot) operation. Figure 2 shows that the foils protrude from the hull in either of two configurations--the surface-piercing foil (which is a permanent, nonretractable structure) and the fully submerged foil. The latter is the design used on the Boeing Jetfoil. Its inherent advantages are that the retractable foils allow relatively normal docking procedures and the fully submerged struts make this vessel less susceptible to wave disturbances, which offers a more comfortable ride. The Jetfoil can also operate hullborne with its foils fully retracted but at exceedingly poor fuel economies and at much lower speeds (between 7 and 15 knots). Floating debris is a potential debilitating hazard for both the surface-piercing and the fully submerged hydrofoil vessels, although less so for the design that uses fully submerged foils.

Air-Cushion Vehicle (Hovercraft)

The hull of this vessel is essentially a flatbed structure. Attached to its periphery is a flexible elastomer seal that protrudes downward and completely surrounds the hull. The air cushion that is created is contained within this seal, so that while the vessel is operating at 40+ knots, only the seal touches the water surface and the vessel itself rides above the water. Since the air-cushion vehicle is amphibious, the seal also supports the vessel over land.

Surface-Effect Vessel (Hovermarine)

The Bell-Halter surface-effect vessel, designed for ferry service and other operations, is a boxlike aluminum structure as shown in Figure 3. Its hull consists of side walls like narrow catamarans. When the vessel is operating off its air cushion as a slow-speed ship, the catamarans offer good ride stability, similar to that of the Vancouver SEABUS. The air cushion, created by fans located below the deck, is trapped between these rigid sidewalls and the flexible elastomer-coated nylon seals that enclose the bow and stern. The vessel is lifted so that its catamaran walls skim along the water surface at 40+ knots. Because of the rigid sides, the surface-effect ship cannot travel over land. However, its off-cushion operating capabilities make it compatible with conventional docking procedures.

VESSEL CONTROL

Conventional Vessels

Traditionally, large ferry vessels, like other conventional ships, divide vessel control between the pilot house (in which steering is performed by rudder adjustment) and the engine room (in which speed is controlled by engine thrust). On double-ended ferries, control is shifted back and forth between the fore and aft pilot houses, although both are manned at all times. Smaller ferry vessels (e.g., the Vancouver SEABUS) may combine steering and speed controls in one pilot house.

High-Speed Ships

Speed and steering control are handled in the pilot house on all high-speed vessel types. Steering is performed by the following means:

Figure 2. Hydrofoil design types.

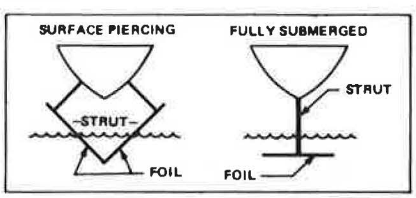
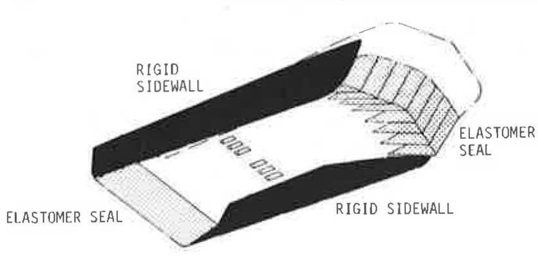


Figure 3. Bow and stern elastomer seal layout of surface-effect ship.



1. Waterjet propulsion units on the Golden Gate Ferry semiplaning ships and the Boeing Jetfoil are used for steering by horizontally deflecting the jet stream.
2. Air-cushion vehicles are steered in either of two completely different ways--deck-mounted fans can be angled independently and used to make steering adjustments or deck fans may be stationary (cannot be angled), which necessitates mounting the rudder behind the fan (as in an airplane tail); in either case, the steering capability is not of a high caliber, since the vessel is riding above the water surface.
3. The surface-effect ship has a marine propeller/rudder arrangement attached to the catamaran side walls.

High speeds are achieved on the air-cushion vehicle and the surface-effect ship only when the air bubble is created and on the hydrofoil only when the foils are protracted. Conventional engine thrust is used to increase speed on the Golden Gate semiplaning vessels.

Fully submerged hydrofoils require a third element of control--the height of the vessel off the water surface--viewed alternatively as the length of the foil protraction. When the vessel is to become foilborne, foil length, direction, and speed are set in the pilot house by using the height-command lever, the helm, and the throttle, respectively. However, an additional automatic control system is also used to constantly monitor and correct foil length in relation to continually changing wave heights. This automatic adjustment system adds significantly to the Boeing Jetfoil capital costs, but it is essential in order to produce an acceptable level of passenger ride quality.

DOCKING PROCEDURES

Two critical elements of ferry-vessel docking are the loading and the unloading procedures for passengers and vehicles. Another is the need to consider variable water heights when designing berthing structures.

Vehicle Loading and Unloading

Many systems use double-ended vessels as a means of minimizing vehicle loading and unloading time. These vessels allow vehicles to drive straight onto the vehicle deck and to disembark straight off the other end.

Some systems incorporate double-ended vehicle loading into a single-ended vessel. When the vessel is berthed with its front headed into the dock, vehicles board and drive straight through to the stern. On reaching its destination, the vessel backs into the dock; this allows the vehicles to drive straight off. The vessel then takes on boarding vehicles via the stern entrance. When returning to the other terminal, the vessel docks head-in, and vehicles disembark by driving straight off, embarking vehicles drive straight through to the rear, and the process repeats itself. Systems opt for the single-ended vessel over the double-ended vessel despite the extra maneuvering necessary, primarily because of the capital cost differential between the two vessel types and occasionally because of the need to use shallow-draft, single-ended ships.

Side- and/or rear-loading vessels are used when quick vessel turnaround is not overly important or when circumstances demand (i.e., narrow river operations in which cross traffic is heavy). Vehicles drive through the boat and around the aft or stern, depending on which opening is used.

Passenger Loading

Since double-ended vessels are selected primarily to hasten vehicle loading and unloading, passengers are normally a secondary concern. They are usually directed along separate ramps and bridges, or else they may use the same ramp space as the vehicles do. Most passenger-only vessels also use ramps or gangways.

The Vancouver SEABUS operation is the only sevice that effectively uses double-ended vessels for passenger loading and unloading. Passengers disembark from six doors located along the vessel's port or starboard side. Meanwhile, doors along the opposite side open soon after and allow passenger embarkation to occur. The separate, almost simultaneous loading and unloading of a total of 800 passengers occurs in 90 s.

PASSENGER AMENITIES

The facilities provided for passenger comfort, convenience, and overall ride enjoyment encompass (a) passenger storage facilities, including seating, standing room, and individualized cabins; (b) food and refreshment opportunities; (c) rest-room facilities; (d) scenic view; and (e) accessibility to the elderly and the handicapped. A wide variety of amenities are provided among ferry operations. Each selects appropriate facilities on the basis of such factors as expected ridership demand, ridership makeup, trip purposes served, and total route travel time. Some amenities, such as available window view and sun-deck space, are tied directly to the type of vessel used. Most passenger-related facilities, however, can be provided in various forms and arrangements on most vessel designs. Some of these facilities are discussed below.

Passenger Storage

Seating type and arrangement ranges from the transverse and longitudinal grouping of seats familiar to buses and subways, used on the Staten Island Ferry and Vancouver SEABUS, to the first-class airline-type seats and seating arrangements, used on the Golden Gate Ferry and available on other high-speed vessels including the Boeing Jetfoil and the Bell-Halter surface-effect ship. Unlike other vessels, the Staten Island Ferry vessels provide considerable standing room, with more than one-third of the passenger capacity estimated for standees.

Scenic View

Ferry systems that cater largely to social and recreational trips normally have considerable sun-deck space available; some have nearly two-thirds of their available seating in exterior locations. Among the smaller high-speed ships, on which sun-deck space is either limited (Golden Gate Ferry vessels) or not possible (hydrofoil), large viewing windows are often used to increase passenger enjoyment. However, even simple vessels of utilitarian design like the Vancouver SEABUS (Figure 1) can incorporate large viewing windows into basic vessel design.

IMPLICATIONS OF JONES ACT

The Merchant Marine Act of 1920, commonly referred to as the Jones Act, specifically forbids the operation of foreign-built vessels for domestic passenger and freight trade. In effect, this act forbids any domestic ferry systems from purchasing any foreign-built vessel, of which there are many among the slow- and high-speed variety. Obviously designed to protect and enhance the U.S. shipbuilding industry and labor force, the act has had the effect of limiting the choice of ferry-vessel design and construction to a relatively few U.S. firms. High vessel costs, long construction periods, and limited design options are the result. The availability of high-speed-vessel manufacturers is particularly limited.

Role of Waterborne Transportation in Urban Transit

ROGER P. ROESS

The initial findings of a three-year study to prepare a manual of planning guidelines for waterborne passenger transportation systems are reported. The various roles played by five major ferry systems in the United States and Canada are investigated to determine the range and flexibility of such services as they form an integral part of an urban or regional transportation network. The conclusion is that the considerable flexibility of the mode as well as the range of technology available provide a great potential for increased use of waterborne systems as a viable modal alternative in many areas, one that should receive greater attention from transportation planners.

Water was man's original form of vehicular transportation. There is historical evidence that crude barge-type vessels were used by early man to transport goods and individuals long before the wheel made overland vehicle-aided travel feasible. Throughout history, nations have developed near and along the world's navigable waterways, from ancient Egypt along the Nile to the original 13 American colonies, which developed as clusters around East Coast waterways.

Access to navigable waterways remains critical to the well-being of nations, and such major projects as the Panama and Suez Canals have literally allowed the economic survival of areas that may well have collapsed. In the United States, more than $1 billion in revenue is earned shipping grain, coal, steel, and chemicals over the nation's 25 000-mile inland waterway system.

Despite the historical significance of waterborne transportation to the affairs of man, a review of travel patterns in U.S. cities reveals that this mode has become the "forgotten man" of urban transportation systems. This is a fact even more incomprehensible in view of the number of large urban areas in the United States and elsewhere that are adjacent to navigable waterways.

Nevertheless, there are more than 600 ferry operations in the United States and Canada today; they range from small private operators that pilot ferries that carry 8-16 cars across narrow waterways to massive public operations, such as those that exist in New York, Seattle, and Vancouver. Moreover, as the investment of resources in highway, rail, and even bus transportation escalates, expansion of the role of waterborne transportation in urban areas has become more attractive.

In March 1979, the Transportation Training and Research Center of the Polytechnic Institute of New York was awarded the first year of a three-year study to prepare a manual of guidelines for the planning of urban ferry systems. The purpose of the three-year effort is to compile relevant information and to develop planning methodologies specific to waterborne services.

The first-year effort, completed in May 1980, has concentrated on various aspects of functional design, including terminal layouts and vessel design. It also included a detailed consideration of the role or roles, both existing and potential, that ferries could conceivably play in urban transportation systems. It is this latter aspect that is treated in this paper.

IMPORTANCE OF ROLE

The question of role is critical to the planner considering any transportation alternative in that it defines how a particular route or service interacts with others to form an integrated transportation system. The question of role is really a composite of many more specific issues, among which are the following:

1. Who is served?
2. Is the service commuter-oriented?
3. What other trip purposes are served?
4. Is the service people- or vehicle-oriented?
5. How is the system viewed politically?
6. How is the system managed and financed?

The answers to these and similar questions define the role that a particular ferry service or system plays in the overall urban or regional transportation system. Understanding these roles is critical if the planner is to be able to consider waterborne transportation options in a rational fashion.

MAJOR FERRY SYSTEMS

One of the best methods of investigating the various roles that waterborne transportation may fill is to study a number of the large and more prominent ferry systems of North America. This paper summarizes the results of detailed analyses of five major systems--those of New York City, San Francisco, and Seattle, and two in Vancouver (the B.C. ferry and the SEABUS). These five were selected for detailed reporting because of the widely varying roles they play and because each illustrates a key or basic potential for waterborne services.

Although references are provided, the majority of the findings reported here are the results of on-site investigations and detailed discussions with the various system operators.

Staten Island Ferry (New York City)

The largest ferry system in the United States and Canada is the Staten Island Ferry, a service operated by the New York City Department of Marine and Aviation. The service carries more than 18 million passengers and 60 000 vehicles/year and is primarily a commuter service between suburban Staten Island and downtown Manhattan. For many years, the ferry was the only direct connection between Staten Island and the rest of New York City, and, despite the construction of the Verrazano Narrows Bridge and the initiation of competing express-bus service, it still carries large numbers of commuters. Ferry terminals at both ends are well served by local bus and rail transit systems (1).

Although the role of the Staten Island Ferry as a major commuter link that carries primarily walk-on passengers is clear, the development of that role has been more or less an accident of history. New York was at one time replete with ferry services: from Brooklyn to Manhattan, from Queens to Manhattan, from Manhattan to New Jersey, etc. One by one, numerous bridges replaced these services, which rapidly sank into bankruptcy and ceased operation. The Staten Island Ferry was the only service to survive as a monopoly into the 1960s, and it remains a considerably more direct and convenient mode to downtown Manhattan for many commuting trips.

It is clear that the Staten Island Ferry is primarily serving walk-on, journey-to-work commuters. The vehicle-carrying role of the ferry has declined since the opening of the Verrazano Narrows Bridge and should not be considered a major role of the service. In fact, two new ferries being purchased for the system will not accommodate vehicles at all and will carry only walk-on passengers.

Its role as a vital commuter link is strengthened by the dense public transit services that link up with the ferry--local buses and the Staten Island Rapid Transit line in Staten Island and the New York City subway in Manhattan. The physical locations of the Staten Island residential communities and the Wall Street central business district also contribute strongly.

The Staten Island Ferry, therefore, is very much a peak-period service; ridership falls drastically in off-peak hours. There is, however, a reasonable percentage of recreational travelers who also use the ferry.

Even more interesting than the Staten Island Ferry itself is the fact that it stands alone in New York as the only nonrecreational or nonsightseeing waterborne service in a city of five discontinuous boroughs largely surrounded by water. The opportunities for additional ferry service are great: from suburban Long Island (numerous points) to Manhattan, from other Staten Island locations to Manhattan, indeed from some of the historic locations in Brooklyn and Queens to Manhattan, and more. The impetus of clogged bridges and highways and capacity-strained rail transit systems has long suggested serious consideration of waterborne alternatives.

Although there has been little concerted effort to investigate new markets for ferry services in and around New York City, there have been some attempts:

1. During the 1964-1965 World's Fair, a hydrofoil service was initiated between Queens and Manhattan. It was, however, expensive and was discontinued after the fair.
2. Arrangements are currently being considered to demonstrate a high-speed surface-effect vessel between Manhattan and several points on Staten Island, but plans are being delayed due to legal and administrative problems.
3. A study sponsored by New York State is currently considering ferry service across Long Island Sound (between New York City and Connecticut) as an alternative to constructing a bridge.

Despite these efforts, however, there is little real momentum for additional services in the New York City area.

It is interesting to note that Long Island commuters took matters into their own hands during a recent railroad strike by hiring numerous fishing "party boats" to make their commute to Manhattan. This measure was technically illegal but served to heighten the importance and potential of the waterborne alternative in New York.

Golden Gate Ferry (San Francisco)

The San Francisco ferry system consists of two routes--from suburban Larkspur and Sausalito to downtown San Francisco. The system is unique in that it is new (initiated in 1977) and was planned, built, and operated with support from the Urban Mass Transportation Administration (UMTA) of the U.S. Department of Transportation (2,3).

The role of the system was clear and well defined in the planning process. The ferry system was and is an alternative to building an additional cross-bay bridge. The system carries about 2000 passengers/day on passenger-only vessels (an UMTA requirement for funding at the time). Vessels use gas-turbine engines for high speed, but correspondingly high fuel consumption and maintenance have been a problem with these engines.

The San Francisco ferries represent a unique experience in federal participation in the urban ferry mode and a unique experiment in using a ferry system as an alternative to bridge construction as a deliberate planning decision. The success of the service was severely hampered by a lengthy labor dispute during the summer of 1979, however, and it may well be several years before the service can be seriously evaluated on two key points: the ability to attract ridership to a new waterborne service and the ability to forestall the need for an additional bridge across San Francisco Bay.

It is interesting to note that the states of New York and Connecticut are making a similar study concerning a bridge across Long Island Sound, as was previously noted. In this case, the bridge plan is publicly unpopular, and a variety of ferry alternatives are under study.

The issue of federal participation in the Larkspur service is interesting in that it sets a precedent. UMTA provided 80 percent of the financing for the new terminal at Larkspur and for three new boats. These were the first such subsidies for waterborne services.

The case for federal support was made easier, since the service is of the high-speed passenger-only type. The suburban terminal is fed primarily by free park-and-ride facilities, although some feeder-bus service is also available. The clear-cut transitlike role of the San Francisco service was a most suitable one for UMTA support. It should be noted, however, that Washington State Ferries and other systems have also applied for similar capital assistance and have been denied. In these cases, however, the systems carry large numbers of vehicles as well as passengers.

Unlike the Staten Island Ferry, the San Francisco system is designed to be a premium service that has a high level of passenger amenities, including plush interior lounge areas and seating, bar service, etc., similar to express-bus and other systems that attempt to lure automobile users to a public mode.

Washington State Ferries (Seattle)

Washington State Ferries operates an extensive system of passenger and vehicle ferries in and around the Puget Sound area. The system includes 11 routes, 22 terminals, and 19 boats and services 17 million passengers and 7 million vehicles per year. The ferries service a variety of users from commuters to vacationers. Many of the islands on Puget Sound are not connected by highway to the mainland, and the ferry system provides a main transportation link among them and to the mainland (4,5).

The system is different from those in New York and San Francisco in two principal ways: (a) it is truly a "system" in that it has many differing routes and services, and (b) its primary users are those who bring vehicles aboard the ferry. Only about 36 percent of the system's passengers are "walk-ons".

The system is historically an old one, consolidated by the state's taking over a variety of private operators in 1951, and serves a dual role in Puget Sound's transportation network. First, the ferries are in a very real sense an extension of the highway system. Second, the system provides the only link to the mainland for numerous water-locked islands in the sound. The broad-based use and acceptance of a waterborne system as an integral and major part of a regional transportation network in Washington State are unique for the United States and again illustrates the waterborne mode's potential.

Washington State's ferry system graphically illustrates the importance and variety of roles that an extensive waterborne network can play in an urban region. The system services commuters and recreational travelers, vehicles and walk-on passengers, and regular and occasional users.

The Washington State ferry system, taken in total, is a regional rather than a strictly urban system, although several of its principal routes to downtown Seattle serve large numbers of regular commuters. It is different in character from the New York and San Francisco systems in that the carrying of vehicles is the primary service component. Further, there are points on the system at which it has a virtual monopoly, because no direct vehicular connections compete or the alternative vehicular routes take a much longer time and are farther than the ferry routes. The system contains commuter routes of 30 min to 1 h in travel time as well as the 3.5-h service to Vancouver Island, which is largely a recreational route.

The system receives no capital or operating subsidy from UMTA or any other federal agency. The state provides operating and capital subsidies of about $11 million/year from the state's motor-fuel tax. Fares are controlled by a public board and are generally set to return 75 percent of operating costs. The lack of federal funding, despite several applications, is generally thought to be due to two factors:

1. The system's emphasis on carrying vehicles rather than people and
2. The fact that a statewide funding mechanism is already in place and providing adequate support.

The first factor, however, fails to recognize the fact that vehicle-carrying ferries are a useful alternative to highway bridge and tunnel construction.

British Columbia Ferry (Victoria, B.C.)

The B.C. ferry system is a large one, which carries 10 400 000 passengers and 3 750 000 vehicles/year on 16 routes. The system, however, is not really urban in any way and services primarily noncommuter travel demands. Most routes run from the island of Vancouver to the British Columbia mainland (and islands in between), and the shortest scheduled run is about 1.75 h. Less than 5 percent of the passengers are classified as walk-ons, and many trucks and buses are serviced (6,7).

The role of the B.C. system is clearly an extension of the highway system. None of the routes serve connections that can be made via bridges or tunnels. This role is reinforced by the way in which the system is financed. For each route operated, the B.C. ferry receives a subsidy equivalent to the estimated cost of amortizing the capital investment required to build the equivalent highway-bridge-tunnel link. This results in an extremely well-financed, highly subsidized system, in which operating funds are not a significant problem.

Although not an urban system, the B.C. ferry system is unique in the public support it receives and in the explicit recognition of its role as an alternative to bridge and tunnel construction. Further, the B.C. ferry system introduces an entirely new role--that of goods movement. Trucks are a major component of the B.C. ridership and provide the major means for transporting goods between Vancouver Island and the British Columbia mainland.

British Columbia Hydro Transportation (SEABUS)

The SEABUS operation in Vancouver, B.C., is unique in the industry in its physical design, concept, and role in the Vancouver urban transportation network.

It is made up of passenger-only service between Vancouver and a northern suburb and was from its inception planned and designed as an integral part of an urban transit system. The system's manager, who is also the developer of the service concept, has a background in the transit industry, not in the maritime industry. Several key elements make this system unique:

1. The intent of the service was to reduce the number of buses crossing the Lion's Gate Bridge, a three-lane facility that is greatly overloaded in peak periods; diversion of automobile users was not a major objective.
2. The docking system was designed specially for the service; boats enter a slip that surrounds the front and two sides of the vessel, with only 1 in of clearance on either side. Transit-type subway doors open on both sides of the ship and are placed about 10 ft apart; passengers exit on one side and enter on the other. The system reduces dock turnaround time to less than 3 min.
3. The vessel's control system features two sets of propellers--one propeller at each of the ship's catamaran corners. Propellers revolve 360°, which gives the vessel a highly responsive and finely tuned control system and allows the smooth docking procedure even though only 1 in of clearance is provided. With all propellers at full reverse, the ship can go from full speed ahead to stop within its own length (100 ft).
4. The North Vancouver terminal includes a bus-and-ride area, but no formal park-and-ride area has been set up. Ridership is high, however; 9500 passengers/weekday and 1250 passengers/weekend day. It is believed that enormous demand would arise if a park-and-ride area were provided, a demand that could not be handled by using only two boats. Additional boats and new routes are being contemplated.
5. The system is subsidized as a regular part of the transit system for 70 percent of its operating expenses.

The SEABUS is a uniquely planned and designed system that represents the state of the art in urban ferry services. The system's physical characteristics were cited as examples frequently in the course of this research. A key point for this discussion, however, is the unique role played by SEABUS as an extension of the transit system, i.e., as an alternative to bus transit. This approach is not only unique but dramatically places before the urban transportation planner greatly expanded horizons for the waterborne option.

CONCLUSIONS

There are many insights that can be drawn from the preceding discussion concerning the current role of ferry systems and, more important, the future potential of ferries in the United States:

1. The role of ferries as a primary form of river crossing has declined precipitously and will continue to decline. Bridges and tunnels are far more efficient in serving as crossings of narrow waterways, particularly where vehicles must cross those waterways.
2. Ferries are nevertheless becoming a more-frequently considered alternative to bridge and/or tunnel construction across more-expansive waterways, such as San Francisco Bay and Long Island Sound, where the cost of bridge or tunnel crossings is prohibitive. In existing services, B.C. ferries and the Staten Island Ferry clearly serve links that cannot be economically replaced by direct bridge and tunnel crossings; even the Verrazano Narrows Bridge is an indirect and time-consuming connection to Manhattan.
3. Ferries serve primarily two trip functions: commuting and recreation. Commuters are daily users and ridership is strongly peaked. The recreational users are occasional and dispersed. A potential exists to exploit the tourist trade (as many sight-seeing services do) for additional income by providing special tour services as part of regular ferry service. Long-haul services are dominated by recreational uses.
4. The role of ferry services in maintaining links between islands and the mainland is a strong one in some existing systems, like B.C. ferries and Washington State Ferries. Many of these are monopolies and are required to maintain habitation of small islands. It is unlikely, however, that such services would be expanded to many island locations that are not now inhabited.
5. Services may be geared to the carrying of vehicles or walk-on passengers or both, depending on regional needs.
6. Ferry services may integrate to form links in a transit network (as in the New York City area and the Vancouver SEABUS) or may form an integral part of a highway system (as in the B.C. and Washington State ferries). They may also operate as relatively isolated services, such as that in San Francisco, which is essentially an isolated transit service, by using park-and-ride as a primary feeder. In some cases (the B.C. and Washington State ferries), the ferry system is in itself a regional network or coordinated system.
7. In long-haul situations, goods movement in trucks may become a significant function.
8. Public acceptance of existing and new systems is relatively high, and on a regional basis, governmental support in the form of subsidies is also strong. Subsidy measures may be either highway- or transit-oriented and generally are indicative of the functional role of the system.
9. Vessel technology (which is discussed in a paper in this Record by Bloch) allows for a wide variety of ships in terms of size, passenger and vehicle capacity, speed, propulsion system, hull design, etc. Essentially, a vessel can be built for virtually any need. The unique and creative use of

conventional technology in SEABUS stands as a tremendous example of the mode's potential in this regard.

Clearly, there is renewed interest in ferries as a viable transportation alternative in many areas. Just as clearly, there exists a potential for a growth of ferry services in many areas, both in terms of new service potentials and of ridership increases on existing services. The Staten Island Ferry, B.C. ferry, SEABUS, and others have experienced strong upward trends in ridership in recent years.

The logic for increased consideration of the waterborne mode is clear: The shortest distance between two points is a straight line. That line often goes over water. The technology has developed rapidly over the past several decades, and many nations have already put it to extensive use. As the resources available for massive land-based transportation systems decline, the water alternative becomes attractive, when available. After all, it is not necessary to construct the right-of-way.

The waterborne mode is not a solution to all our urban transportation problems. It is, however, a most flexible mode that can fulfill a variety of functions and roles. At the very least, it should be a more prominent option considered in situations in which it is available. Over the next two years of the current work, it is hoped that tools will be provided to aid the planner in this consideration.

The potential for waterborne transportation as a viable modal alternative has only been very lightly tapped. It is indeed ironic, but in the years to come, man may return to his original form of transportation to help alleviate the urban congestion being experienced in the more modern modes.

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Waterborne Access to Gateway National Recreation Area and Other Waterfront Recreation Areas by Passenger Barge-Tugboat Combinations

S. DAVID PHRANER

Examples of barge-tug operations are common on the waterways of America. Few (probably less than 20) exist in passenger-carrying forms. None exist that use a range of new technologies in barge-tug integrator systems for passengers. Approximately eight to ten of these barge-tug integrator systems now exist and are providing efficient movement of bulk goods. The basic feasibility of applying this technology to a unique passenger-transport need is addressed here—that of connecting large centers of population by using regional-scale waterfront recreation complexes. Gateway National Recreation Area, located in the New Jersey-New York region, is the second most visited National Park facility. Its access problems are unique and require innovative approaches. Barge-tug integrator systems exhibit characteristics that qualify them for consideration. It is estimated that modest but significant savings in capital and operating costs can be achieved by barge-tug integrator systems over conventional excursion vessels. In addition, the barge-tug combination provides some unique advantages in labor and vessel use, safety, joint use, and adaptability to purposes of recreational travel. Although barge-tug systems do have potential for application to recreation access, these advantages do not extend to use for the journey to work or for premium recreation.

The Tri-State Regional Planning Commission's involvement in water transit commenced with staff analysis of existing and past waterborne operations in the region. An analysis of the state of the art in waterborne modal technology was completed and used in an analysis of a ferry across Long Island Sound performed by Tri-State for Connecticut and New York. This study has recently been renewed. Most recent involvement is a demonstration of waterborne technology in several regional transportation applications. In addition, waterborne transportation is being considered for access by large numbers of seasonal vacationers to the Gateway National Recreation Area.

Regional, local, and federal agencies and other interested parties have cooperatively been treating the dilemma of providing efficient, enjoyable access to Gateway and other major recreation areas of the Tri-State Region. Access by waterborne transit has been particularly difficult to implement because of the following five obstacles:

1. Lack of marine operators to provide boats and service,
2. Legislative restriction on the National Park Service (NPS) to undertake transit access improvements outside the parks,
3. Diminished construction of excursion boats,
4. Lack of acceptable or available docking facilities, and
5. Lack of year-round investment due to seasonal nature of demand (vessel and personnel inactive nine months of the year).

In spite of these formidable obstacles, the notion persists that access to Gateway by water is an appealing, attractive transportation alternative for the following reasons:

1. All six of the Gateway geographic units are located on navigable water channels but are otherwise isolated from high-capacity mass transit;
2. Five of the units are or had once been served by high-capacity water transportation from urban locations such as Harlem, lower Manhattan, Jersey City, Brooklyn, and Newark;
3. A demonstration was conducted during the summer of 1976 that confirmed the popularity of waterborne access to recreation;
4. All units of Gateway are based on waterfront themes;
5. Gateway attracts the second highest number of visitors to a national recreation area and thereby requires unique applications of transportation technology; and
6. Proposals for access to Gateway by land routes have proved unpopular with the communities through which access is furnished (this problem is becoming more apparent as Gateway transportation planning advances, but water access can be designed to provide direct access by passing these potential trouble spots on land).

BARGE-TUG CONCEPT--NEW TECHNOLOGY?

This paper recognizes the waterside characteristics of Gateway and addresses all five major obstacles to waterborne access. This is not intended to be the ultimate or completely detailed analysis of the barge concept but rather to initiate further technical analysis by naval architects or experienced marine operators.

The barge-tug concept is not new. The region's harbors and waterways have had tugboats towing or pushing lighters, stickboats, carfloats, and other barges for more than a century. With few exceptions, these activities have been directed at movement of goods rather than people. The best land-based analogies to the barge and tug are the tractor-trailer or locomotive-hauled rail cars. Special benefits occur when the power or propulsion unit is separable from the cartage unit. These benefits change with time and technology, but some always remain.

Early steamboats on the Hudson River did pull passenger barges in a variation of the barge-tug concept. The reason for this arrangement was to avoid casualties from the all-too-frequent steamboat boiler explosions and fires. Immigrants were transported to and from Ellis Island by passenger barge. In both of these applications the powered and nonpowered vessels were in convoy with one another. In the event of mishap with one, the other could rescue survivors. This benefit remains today for barge-tug combinations but on a diminished scale and for somewhat different reasons. The danger of fire has decreased considerably because of steel hulls and superstructure, and the danger of boiler explosion has disappeared because of the marine diesel engine. The constant presence of another vessel or vessels is an important criterion in determining regulations to be followed in vessel design, even to this day. The barge-tug concept shares this advantage with its earlier counterparts.

In its simplest form, the concept is a conventional tugboat that pushes a conventional barge by using a notch or other device built into the stern of the barge (Figure 1). This system has been found to be more efficient for medium to long distances than towing from alongside or from the bow of the barge.

A new technology has emerged in waterborne freight movement, which in its present state of the art includes several variations of the basic barge-tug combination:

System	Name	Originator
Rigid barge-tug integrator	Catug	J.B. Hargrove/Seabulk
	Breit/Ingram	Breit and Garcia
Flexible barge-tug coupling	Seebeck	A.G. Weser
	Sea-Link	L.R. Glosten and Associates
	Artubar	Transway International
	Barge Train	Barge Train, Inc.
Barge on vessel	Barge Integrator (the Floater)	Mitsui Zosen (four Japanese shipping companies)
	Lash (lighter aboard ship)	

The major differences in these technologies are in the barge-tug coupling systems and the degree to which the barge and tug are integrated into a single unit. In the most-sophisticated systems, the tug is a specially designed vessel that acts in effect like a detachable power unit. In combination under way, the barge-tug resembles a large conventional bulk carrier. These variations in technology are illustrated conceptually in Figure 2. All these systems are operational except the Floater. All are applied to ocean as well as coastal or lighter-duty service. Most systems are relatively new and have been implemented in the past decade. However, the earliest concept, by George Sharp, has been in service for 27 years.

Barge-tug integrated vessels vary in size. Most barges are from 300 to 500 ft long, but the largest are more than 950 ft long and travel 12-15 knots when loaded. Several have operated through hurricanes in the loaded state or in ballast. They are estimated to save more than 20 percent in operating costs and approximately 15 percent or better in capital costs compared with a conventional vessel.

APPLYING BARGE-TUG CONCEPT TO PASSENGER TRAVEL

Which of the systems in the array of technology are most adaptable to Gateway and other passenger-recreation purposes? Catug and the Floater can be screened out as difficult or undesirable to adapt to the dual or passenger-carrying function. Among the other alternatives, the best choice may depend on ownership and intensity of service. Two ownership strategies are possible for study to optimize the utility of the concept:

1. Agency owns barges and leases general-purpose

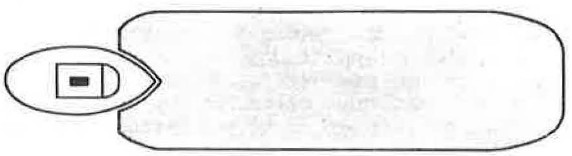


Figure 1. Barge-tug concept, conventional form.

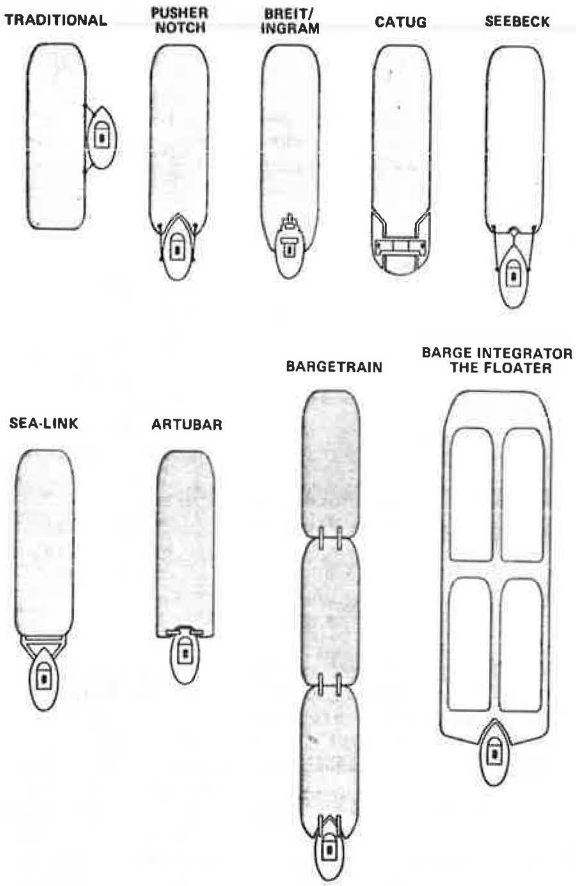


Figure 2. Variations of barge-tug new technology.

tug(s) for hours, days, weeks, months, or season; and

2. Agency owns full system of barges and tugs specially equipped by using one of the advanced technologies.

The full-ownership strategy recognizes that private tugboat operators would likely be reluctant to undertake purchasing new vessels or to retrofit their tugs by using the specialized hydraulic rams, flexors, yokes, or unique bow configurations to accommodate the alternatives that are more radical in concept. Besides the additional cost, the design refinements might render this vessel less flexible in its assignment to more conventional tugboat duties, which is a key to the success of this concept. Some of the alternatives, such as Sea-Link, which has detachable push knees, can be implemented with little additional hardware cost on the tug. The full-ownership strategy assumes, however, that the tug can be leased to an operator to perform conventional duties during the off season.

Regardless of the specific technology alternative used, two modes of operating control are possible. A profile of the resulting passenger barge-tug combination might appear as shown in Figures 3 and 4. The two operating modes differ mainly in the presence or absence of a barge pilothouse for remote control of the tug. The barge equipped with a pilothouse may be only slightly more costly but has the advantage of being mated with a conventional tug. The barge that has no control requires a tug equipped with an elevating pilothouse. The nature and extent of remote control can vary from telephonic or radio messages to direct electronic control by marine telegraph on the bridge of the barge that controls a similar unit in the tug pilothouse and engine room.

Based on these and other considerations, the use of tug-propelled barges for passengers is possible. However, is it feasible? Clearly, the concept has some serious limitations. Below a certain capacity (500-1000) it becomes impractical to use the barge-tug concept. It is most economical in its largest applications, whether it carries passengers or freight. It will be a relatively slow-speed mode that ranges around 10 knots. This is a slightly slower speed than that of the current Circle Line Liberty Island boats. For this reason alone, the use of passenger barges will be limited to recreational travel, for which the leisurely pace is consistent with the sightseeing and excursion nature of the trip. Cost, safety, and other factors should and will be addressed, but a short review of the rationale behind the employment of these technologies is required first.

RATIONALE FOR BARGE-TUG SYSTEM IN EXCURSION SERVICE

The following list gives the rationale behind this paper and forms a summary on which to build additional technical work:

1. Precedent exists for the barge-tug concept in most rigorous ocean-going cargo transportation. Twelve barge-tugs are currently being constructed under Title 2.
2. Regional precedent exists in the St. John's Guild Lila A. Wallace and four previous Guild-operated passenger barges in service since 1870. These barges have been carrying children, the handicapped, and the elderly on marine excursions. A passenger barge was built recently for California's Mare Island Ferry. Other, small-scale examples of barge-tug combinations of passengers and vehicles exist.
3. Barge-tug systems use existing proved technology, equipment, and carriers.
4. There is contract flexibility; numerous towing services and vessels exist to compete for service contracts.
5. Capital cost savings have been estimated to be at least 12 percent more than those of comparable powered vessels. In addition, fewer revenue vessels are required (four powered passenger vessels versus three passenger barges).
6. The potential exists for optimal use of personnel resources during 12 months rather than 3 months of the year.
7. More effective use of capital can be realized (seasonal use of barge, 12-month use of tug's propulsion).
8. Operational potential is created on all navigable waterways of the Tri-State region; the vessel has moderate draft and is accessible to most Gateway sites.
9. Tugs are freed for other commercial work during long layovers at the recreation site or other recreation nonpeak periods.
10. Long layovers at park sites enable use of the barge as a portable substitute for land-based

Figure 3. Conventional tug, pilothouse on barge (radio or remote control from tugboat).

Figure 4. Elevated pilothouse on tug, no pilothouse on barge (direct control on tug).

facilities at the park. Such functions might include bathhouse, snack bar, auditorium, or kitchen.

11. Extra safety and life-saving services are provided, since the independent vessel (the tug) will always accompany the primary vessel.

12. The barge can be converted (although not without redesign) to a self-propelled vessel by installing Harbormaster or other add-on propulsion unit packages. Confirmation of this point should be made during a detailed study.

13. The excursion vessel, whether powered or not, is extremely adaptable for use by the elderly and the handicapped. In fact, systemwide this mode is more adaptable than bus or rail in providing access to recreation for these groups.

14. Little or no fuel is carried on board the passenger barge, which diminishes fire hazards and attendant regulatory requirements.

15. Since it is a seasonal vessel, no heat or air conditioning is required on the barge. Power requirements for lights, etc., may be furnished by the tug auxiliaries or by on-board diesel generators.

16. Control while the vessel is under way is optional; it may be on the tug or remote from the barge. Dual control is possible and desirable.

17. Speeds achieved by barge-tug combinations are appropriate to the excursion and recreation-access function.

CHARACTERISTICS OF TUG AND BARGE IN RECREATION SERVICE

Like the transit system of the Tri-State Region, tugboat operations present many contrasts. The smallest operations have one or two small craft, whereas the largest operates a fleet of nearly 25 tugs in New York Harbor and 90 or so along the Eastern Seaboard. The Tri-State Region has more than 35 marine towing operators based in and around the metropolitan area.

Capital Cost

Capital cost is a consideration if an agency is to undertake ownership rather than lease tugs. Cost varies with the vessel size, horsepower, and design. Unit costs are lower for purchase of a "class" tug (three or more units), and the vessel price diminishes in proportion to the increase in class size. This is based on a custom design. "Stock tugs" based on standard off-the-shelf specifications and designs generally are lower in unit cost than the custom designs whether the latter are purchased in classes or not. A typical custom-built class tug in the 2000- to 3000-hp range that is 90-100 ft long will cost an estimated $2.5 to $3.0 million (1980 dollars). A well-maintained tug in intensive service will have a life expectancy in the 30-year range.

The cost of a passenger barge is difficult to estimate. The only accurate index of cost is the Lila A. Wallace of St. John's Guild. This barge is a reasonable prototype for a Gateway access vessel, although a passenger capacity of at least 2000 per barge is more desirable. Lila A. Wallace carries 1200 passengers and is 181 ft long. The cost was $2.0 million in 1974 ($11 050/ft). For comparison purposes, the 280-ft Dayliner of the Hudson River Day Line cost $3.5 million at about the same time ($12 500/ft). There is a capital cost savings of at least 12 percent if a nonpowered excursion vessel is used rather than a powered one. This saving is very conservative in view of the specialized equipment found on the Lila A. Wallace (for example, that barge has a fully equipped dental clinic). Additional savings are estimated if four powered excursion vessels operate on the same schedule as three barges.

If the barge owner elects to purchase tugs, a new barge-tug combination is estimated to cost in the neighborhood of $5 million. Six bulk Catugs are on the ways now; the total cost is $54 million, or about $9 million each. They are more than 660 ft long, however. This substantial additional cost of the tug may be recovered by the owner through leasing out the tug during nine months of the year. The cost is diminished further when it is considered that good scheduling should require fewer tugs than barges (see Figures 5 and 6, discussed later in this paper).

The agency that owns or operates the barge may choose to lease rather than to purchase tugs. Indeed, this may be wiser, at least during the initiation of the service. The purchase rather than lease of tugs means, in effect, that the barge operator is entering the tug business. This is not the type of business to undertake parttime. It is highly competitive, capital- and labor-intensive, and is fraught with complex labor and regulatory requirements. Of the experts interviewed for the preparation of this report, none regarded the purchase of tugs as preferable to leasing, particularly when the lease would cover only three months of the year.

Operating Costs

The operating costs of a tug vary. Tug operators have different cost schedules for harbor and for coastal services. Tugs are available with or without crews and by the hour, day, week, month, or season. Again, the nature and amount of use are reflected in the cost. A typical harbor schedule reflects an hourly rate for weekdays of $180. For weekends the rate rises to nearly $230/h. There is little difference between summer and winter rates. Good weather in the summer encourages shippers to schedule more traffic. Winter oil-movement peaks compensate for the good-weather traffic. One is left with the impression, however, that tugboats are available as much or more during the summer peak recreation months as during the winter months. This is an extremely important factor in a transit business, in which traditionally the excursion operator must recover the investment during the three summer months, and therefore service is priced accordingly. Again, for comparison purposes, based on the harbor fee schedule, an 8-h weekday excursion would cost $1440/day. This assumes a total commitment of the vessel and crew for that day. In fact, the tug could be free for four or more hours during midday for other duties as assigned by the operator's dispatcher. In any case, the fee for an 8-h day for a 500-passenger Circle Line vessel is $1800 or $225/h. Although the comparison is somewhat obscured by other considerations, such as the larger barge capacity and crew costs, the magnitude of savings is estimated to be around 20 percent for a leased barge-tug over the lease of an excursion vessel.

Unfortunately, the St. John's Guild passenger barge cannot be used as an indication of barge operational cost. Its annual operating budget is around $400 000, or about $4500/day. However, its season is restricted. Also, it has an expensive professional staff not connected with the operation of the vessel, such as therapists, physicians, and dentists. In addition, the vessel is used year-round as a clinic and for other nontransportation purposes. It makes only one relatively short trip daily and as a charity gets a favorable rate from the tugboat operator.

Unit costs for operating the tug in contrast to leasing it were unavailable. Based on estimates of crew, fuel, overhead, and other costs, harbor tug operation appears to fall within the range of $120-$150/h.

Crew requirements are established commensurate with the service. The current harbor-tug operations crew consists of five or six men, as follows: either captain, mate, two deckhands, and an oiler, or the first four plus a cook and an engineer. Crews for tugs in coastal or ocean service are larger by two or three members.

The crew size for the barge is difficult to estimate. Again, the one precedent in the Tri-State Region, and perhaps the nation, is the Lila A. Wallace. This vessel is manned by the following operations crew of nine: captain, mate (who may be unlicensed), chief engineer, assistant engineer, and five to eight deckhands.

The combination of tug and barge crews results in a total crewing requirement of from 15 to 17. A new technology connection between barge and tug might reduce this number somewhat. Personnel requirements for optional food service, entertainment, medical service, or other programming would be in addition to the operations crew. These nonoperating personnel do have an important lifesaving function, however. That these personnel have basic emergency training is recognized by the U.S. Coast Guard in determining vessel safety requirements.

Speed, Draft, and Seaworthiness

Speed, draft, and seaworthiness are important considerations in applying the barge-tug to recreation access in the Tri-State Region. Speed is probably the least important of these considerations, at least to the passengers, because of the recreational nature of the trip. [Certain recreational boat trips (those of the Circle Line, for example) require strict adherence to a demanding schedule, or vessel use would be impaired. This is a consideration for the operator rather than the user, however.] The largest barge-tug combinations operate in ocean service routinely in the average range of 12-15 knots. In harbor service that used a modestly powered tug, the range would likely drop to the 10-knot average. By way of comparison, the following powered excursion vessels are operating currently at the speeds indicated:

Name	Power (hp)	Speed (knots)	Capacity	Length (ft)
Miss Circle Line (1964)	940	12	750	139
Miss Liberty (1954)	800	12	1037	121
Dayliner (1972)	3500	16	3232	280
Good Time II (1976)	700	12	500	86
Island Queen (1974)	550	13		120
Provincetown (1973)	1800	16		135

In the case of barges, the speed depends on the characteristics of the tug in combination with the dynamics of the barge. Consistent speeds are therefore impossible to estimate. It appears from comparative data furnished above that a 12-knot maximum speed is a reasonable estimate. The Lila A. Wallace, in an unwieldy towing arrangement with a tug alongside, manages a maximum of 11 knots.

Draft is an important consideration in planning applications for barge-tug technology. Again, as with speed, the tug rather than the barge imposes the limitation. The Lila A. Wallace, for example, draws only 6.5 ft. The barge can be designed to provide a relatively shallow draft, certainly no more than 10 ft in the loaded state, without loss of stability. However, all tugs, in order to fulfill their primary functions well, must "dig deep" with their propellers and steering gear. This deep hull configuration is a characteristic of the tugboat so that it can exert maximum directional forces on the object to be moved. Ocean-going tugs characteristically have an 18-ft draft. Harbor tugs have somewhat less but range from a 12- to a 15-ft draft. This characteristic of tugs represents a serious drawback in applying the barge-tug technology concepts to recreational purposes in the Tri-State Region. An examination of the region's navigation charts reveals that there are several potential recreation areas that have water-depth limitations. These depth limitations fall generally into two categories: channel depths to recreation sites that prohibit direct access by tugs and the location of deep channels that reduce routing flexibility and require route circuity. Specifically, the following regional recreation sites are limited by the following minimum channel and docking depths:

Chart	Location	Depth (ft) Channel	At Dock
282	Bear Mountain	90+	30+
222	Rye Beach	20	17
369	Sandy Hook (Fort Hancock)	21	23
369	Sandy Hook (Horseshoe Cove)	19	12
542	Floyd Bennett Field		
542	Breezy Point (Fort Tilden)	19	26
542	Breezy Point (Coast Guard dock)	19	26
542	Jamaica Bay-Canarsie Pier	27	22
286	Great Kills	10	12
369	Ellis Island (southeast entrance)	19	13
369	Liberty Park	21	20
369	Liberty Island	34	13
369	Fort Wadsworth	51	71

At the origin end, all urban docks are on deep channels, except possibly Newark. The Passaic Pier at Newark (chart 287) and intervening points reach 15 ft at high water. Inner Jamaica Bay and Great Kills units of Gateway represent the areas inaccessible by tugboat because of insufficient depth. Fortunately, none of these sites, except possibly Great Kills, represents a major excursion-vessel destination. The Jamaica Bay unit is more adaptable to the small-scale nature tour such as that provided by the 250-passenger Rockaway Boat Line craft currently being operated.

Seaworthiness is an issue that is strongly related to the next topic discussed here, safety and regulation. It is the state of a vessel and the combination of its design and condition that result in fitness for service. Because of the predominance of children on board excursion vessels, special care should be exercised in the design and stability of the barge. In particular, in Gateway service it must be able to sustain the conditions of semiopen water in Raritan Bay and off the Rockaways.

BARGE-TUG REGULATION AND SAFETY

Like self-propelled vessels, barge-tug excursion service is subject to two forms of regulation: vessel service and inspection and certification of vessel and crew.

Interstate services are regulated by the Interstate Commerce Commission except when they fall entirely within a single harbor. It then becomes a local matter. The state, counties, and to some extent the municipalities are interested in varying degrees in "local" marine services. In the case of local marine services in New York, the state has enabled counties and/or municipalities to regulate routes and fares. Marine services to federal lands are usually governed by the appropriate federal agency and regulation is usually achieved by the bid-contract arrangement. The National Park Service's Sunken Forest on Fire Island and Liberty Island Park furnish regional examples of this type of regulation, which presumably would apply to Gateway.

Inspection and certification of vessels and crews are performed by the U.S. Coast Guard exclusively. Vessels and crews are certificated by functional type of license and geographical scope. The inspection and certification decision making is routinely decentralized to the district level and, in some cases, below that. The motivation behind this type of regulation activity is primarily safety. In summary, several interrelating factors of safety apply to vessels, whether barge or self-propelled:

1. Lifesaving equipment;
2. Fireproofing and fire-fighting equipment;
3. Stability;
4. Structure strength (hull and superstructure);
5. Miscellaneous (sanitation, control systems, and auxilaries); and
6. Propulsion-boiler-fuel systems (not applicable to barges).

Lifesaving equipment serves as an example of regulations that apply to barges. The special considerations (vessel capacity, distance from land, water depth, operating season, etc.) that govern the amount and location of lifesaving equipment carried on board are stated in Title 46, Code of Federal Regulations, Subchapter H, Sections 75.10-20(a)-20(c), May 1, 1969. Other considerations that mitigate a more relaxed regulatory attitude toward Gateway barges are the presence of an auxiliary vessel, little or no fuel carried on board, and proximity of grounding depths. These characteristics are taken into consideration when the vessel is certified by the U.S. Coast Guard. The barge specifications and equipment should be reviewed by the U.S. Coast Guard and concurred on before construction begins for all five major items of inspection and certification.

Fireproofing, fire-fighting, and structural and stability requirements are related. They, with little exception, are integral characteristics of the vessel. They are not easily added on or changed. Therefore, care in ensuring that barge specifications meet U.S. Coast Guard requirements is critical. These "permanent" vessel refinements reduce the likelihood that the barge may be used for other than excursion travel to recreation. Stability can be simulated on paper by using an appropriate formula. Requirements for structural design, fire-retardant materials, fire zoning and location, and number and dimensions of points of egress are matters for early discussion among naval architects, engineers, shipbuilders, and the U.S. Coast Guard. In a sense, each vessel class is a unique case that requires special consideration.

A listing of the specific requirements that would be placed on a barge is impossible now because vessels used exclusively in a local area may be subject to some discretionary treatment by local certifiers. There are few examples of passenger barges. During the preparation of this report, none became known that employed new technology linkages between the barge and the tug. Faced with this lack of precedent, the U.S. Coast Guard at a maximum could impose on a passenger barge the same requirements as those imposed on a self-propelled excursion boat. However, it is more likely that passenger-barge requirements for local service would be less stringent.

BARGE AMENITIES AND MULTIPLE FUNCTIONS

The Lila A. Wallace represents probably the ultimate in a passenger-carrying barge. Its use during 12 months of the year for health services requires high-quality amenities for the climate control, food preparation, sanitary treatment, and health-oriented programs presented on board. St. John's Guild's former vessel Loyd Seaman (now the Robert Fulton) represents a more suitable prototype for excursion or recreation-access service. The Loyd Seaman was the last of the guild's passenger barges used exclusively during the summer. It required no heating or air conditioning. The same would be true of an excursion barge unless it was used for some stationary purpose during the winter.

As a seasonal excursion vessel, a barge is a relatively austere utility vehicle. However, secondary functions in support of activities of the NPS program may dictate features that depart from the conventional excursion-vessel design. These secondary functions could include a bathhouse; an auditorium for NPS interpretive and other presentations and group activities; a cafeteria or other food service, preparation, or distribution facility; a contingency shelter in the event of inclement weather; a medical facility; a winter storage facility; and off-season conveyance for construction and other park-related material.

Since most functions are relatively compatible and the vessel is sizable, the barge could be designed to perform all these functions by easily implemented conversion of space. Because the propulsion system and crews need not accompany the barge through its entire operational day, a land-based NPS crew can man the vessel while it is performing nontransportation park functions. This is a particularly appealing feature of an excursion barge. As Gateway grows, permanent park facilities may not be ready for use or may be of insufficient size to handle unusually heavy crowds. After it performs its primary transportation function, the barge, in effect, becomes a part of the park facilities. Its location among the units of Gateway can be scheduled according to the changing needs of park operation, month to month or year to year.

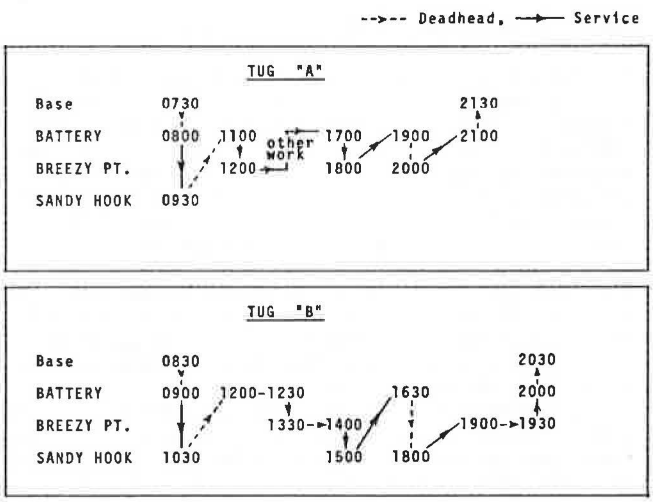
Again, as pointed out in the previous section, care must characterize the design of the vessel to enable it to fulfill all its functions efficiently and to meet regulatory requirements. For example, it would be difficult for an auditorium in the vessel to exceed approximately 130 ft in length because of a regulation on the maximum size permitted for fire zones. A schedule is also critical to the multifunctional role of the barge. Arrival and departure times must allow sufficient time to enable completion of programmed activities.

BARGE AND TUG SCHEDULES DURING PEAK SUMMER DAY

A sample schedule has been compiled as an attempt to optimize use of barges, tugs, and crews while a large number of people are being conveyed efficiently to and from the units of Gateway. Two scenarios, one for barges and one for tugs, have been drawn up (Figures 5 and 6); they assume the following elements:

1. Two tugs;
2. Three barges;
3. Running times from Battery to Sandy Hook of 1.5 h, Battery to Breezy Point of 1 h, and Breezy Point to Sandy Hook of 1 h; and
4. Dwell time of 0.5 h to load and unload.

Figure 5. Detailed tug scenarios for Gateway service.



The resulting scheduled departure times appear as shown in Table 1.

One barge lays over at Sandy Hook from 1030 to 1500 and another from 1500 to 1800 (Figure 6). At Breezy Point, layovers are from 1200 to 1800 and from 1800 to 2000. In both cases, the layover enables use of the barge for a food-service function and other activities. The tugs would be in continuous service (0800 to 2130 for tug A and 0900 to 2030 for tug B). Tug A would be available to the tug dispatcher between 1200 and 1700 for conventional, nonrecreation assignments. The tug and barge transportation utilization rates are different, which reflects greater use of tugs for transportation than barges or, for that matter, greater than is possible for self-propelled excursion boats. Tug utilization rates in terms of hours daily and percentage of time for two tugs are as follows:

Item	Daily Hours	Time (%)
Revenue service	13.5	52
Deadhead (light)	6	23
Dwell time (loading, etc.)	1.5	6
Layover	0	-
Other revenue service	5	19
Total	26	

For three barges, the rates are as follows:

Item	Daily Hours	Time (%)
Revenue transportation service	14	41
Deadhead (light)	-	-
Dwell time (loading, etc.)	9.5	30
Layover (land-based service)	10.0	29
Other duties	0	-
Total	34.5	

It was estimated that four or five conventional excursion vessels that had a reduced utilization rate would be required to run a similar schedule. Additional refinements in the schedule to optimize crew costs were not performed.

This schedule, which uses barges of 2000-passen-

Figure 6. Detailed barge scenarios for Gateway service.

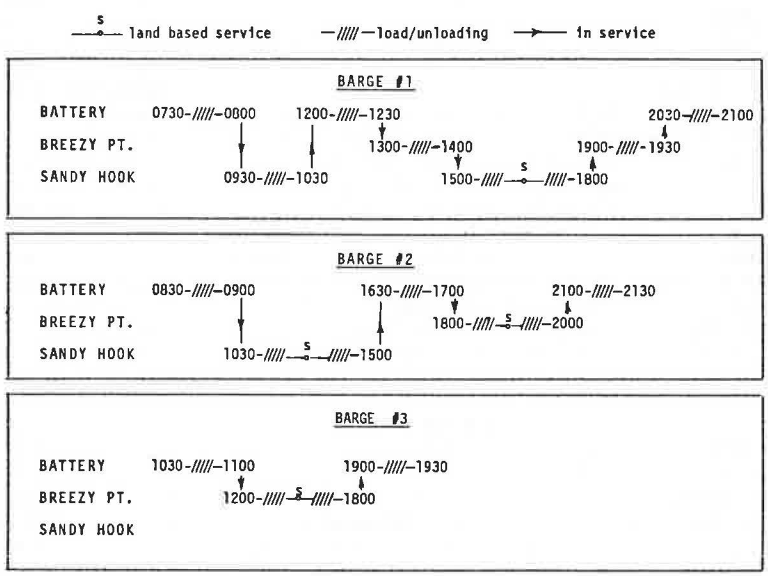


Table 1. Barge-tug departure times: sample schedule.

Direction	Destination: Battery-Sandy Hook	Battery-Breezy Point	Breezy Point-Sandy Hook
Going	0800	1100	1400
	0900	1230	
	1230[a]	1700	
Returning	1030	1800	1800
	1500	1930	
	1800[a]	2000	

[a]Intermediate stop.

ger capacity, could conservatively deliver 10 000 persons to two Gateway units, perform an intrapark round trip, and furnish food service during lunch and dinner periods at both units. By way of comparison, this is the rough equivalent of about an 85-bus fleet (50 buses that make 3.5 round trips to Sandy Hook and 35 that make 5.5 round trips to Breezy Point) working at capacity. At an average occupancy rate of four persons per automobile, the equivalency is 2500 automobiles. Manning requirements between buses and barges indicate that the barges save about 30 person-days every operating day. For all the 55-day summer seasons during a 30-year life of the barge, this labor cost savings would nearly amortize the vessels. This assumes that the capital cost of the buses is borne elsewhere and is not included in the cost comparison. Of course, the tugs and buses could be used all year, whereas the utility of the barges during the winter season is limited.

RECOMMENDATIONS

Although much of the work here assumes that a three-barge, two-tug system would be implemented, much needs to be resolved about the practicality of the concept and which barge-tug linkage technology is most suitable. Therefore, rather than making detailed proposals, I feel that the barge-tug concept as presented in this report should be passed along to the various appropriate planning, operating, and regulatory agencies for review. From this review, a lead agency should be selected to sponsor and draw up a request for proposal for a response by a naval engineer or an architectural firm. The specific action to be taken in establishing a passenger barge-tug fleet for service to Gateway would be based on the findings of that investigation.

The integrated barge-tug is a recreation-dedicated system. It is unacceptable for conventional journey-to-work transit. This system competes with the concept of joint use of transit buses and trains during off-peak periods. In spite of this, it is a multiuse system in that there is year-round deployment of the tugs and stationary uses of barges. The funding source implications of the multiuse aspects require further study as well.

ACKNOWLEDGMENT

I would like to acknowledge interviews with personnel from St. John's Guild, the Maritime Administration, various tugboat operators, and U.S. Coast Guard vessel inspection officers.