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The Impact of Inland Waterway Lock Congestion Upon Barge Shippers

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I. INTRODUCTION

LOCK CONGESTION in the inland waterway network is an important determinant of the performance of barge transportation, affecting shippers, carriers and public policy investment decisions. The delay of barge tows at congested locks increases transit time, operating costs, and reduces equipment utilization. Cost increases induced by lock delay are ultimately absorbed by barge shippers in the form of higher linehaul transportation rates or surcharges. In addition, waterway shippers' non-transportation logistics cost components, such as inventory carrying costs, may also increase as a result of lock congestion. Ultimately, waterway shippers may divert to other modes of transportation which become relatively less costly as lock congestion increases.

The impact of lock congestion upon transportation rates and waterway shippers is an important determinant of the economic justification for present and future structural improvements to the inland waterways system.[1] Over the past decade, economic models used to evaluate waterway improvements have hypothesized shippers' responses to changing levels of lock congestion. Empirical analysis has not been undertaken, however, to verify the net impacts of lock congestion upon shippers and demand for waterway transportation.

This paper focuses on three important interrelated aspects of the impacts of lock congestion upon waterway shippers. The first aspect is the measurement of short-run lock congestion impacts upon waterway shippers. Past efforts to assess the effects of lock congestion have tended to focus upon hypothetical long-run impacts on waterway shippers. Lock congestion occurs and shippers are assumed to adjust in some optimal fashion. No assessment is made, however, of the possibility that shipper behavior may change over time or of possible short-run response mechanisms.

The second aspect is the manner in which shippers respond in the long-run to sustained levels of lock delay. While this is related to the measurement of short-run impacts of lock delay, specification of long-run impacts is necessary to determine how shippers ultimately respond to congestion. The long-run impacts of lock congestion reflect shippers' production and logistics requirements. Shippers' responses to lock congestion will be influenced by their planning horizons and sensitivity to delay.

The third aspect of lock congestion is the implication of research on this topic for the imposition of congestion tools and user fees. Past estimates of the impacts of imposing waterway congestion tolls or user fees have generally been predicated on a relatively limited set of shipper responses. If shippers' responses are not correctly specified, the estimated impacts and revenues from congestion tolls and user fees are likely to be incorrect. Given the current legislative debate over the form and level of user fees, lock congestion impacts upon shippers are important if the inland waterways are to be maintained and operated as an efficient transportation system.

II. SIGNIFICANCE OF LOCK CONGESTION:

The significance of analyzing lock congestion impacts originates from the monopoly position of the Federal government in providing the inland waterway system. Locks are not owned or operated by users, consequently waterway shippers are unable to alleviate lock congestion by structural measures. Structural changes on the waterway are only undertaken when aggregate shipper behavior dictates remedial action. In the absence of congestion tolls or user fees individual shippers do not have have the incentive or ability to initiate nonstructural measures to improve the overall efficiency of lock operations.

The inability of individual shippers to alleviate lock congestions results in absorption of delay costs until an alternative mode of transportation becomes less expensive. After a threshold level of delay cost is reached shippers will divert from the waterway to alternative modes of transportation. The hypothet-

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ical impact of lock congestion consists of two distinct effects. First is the direct cost of delay and second is the non-transport logistics costs incurred as a result of larger inventories due to increased transit time and delay.

The significance of lock congestion to shippers is that it represents a change in the relative price of waterway transportation over which they have virtually no direct control. Although any individual shipper can choose to avoid lock congestion through a variety of alternatives, his choice will have a negligible impact on the overall level of congestion. Each alternative to lock congestion has some cost associated with it such that shippers compare the increased cost of lock congestion with the increased cost of alternative transportation patterns.

When individual shippers have a finite number of non-structural responses to lock congestion, their alternatives can be analyzed to determine optimal transportation patterns. This is a formidable task to be performed separately for each waterway user, however. When shippers and receivers are aggregated to identify non-structural responses to lock congestion, the elasticity of demand for waterway transportation can be analyzed.

III. SHIPPER RESPONSE TO LOCK CONGESTION:

1. Research Methodology

Previous research has indicated that barge shippers may be relatively insensitive to the impact of lock congestion upon non-transport logistics costs.[2] In order to test this hypothesis it was necessary to operationalize logistics total cost models for barge shipments affected by lock congestion. The purpose of logistics total cost models was to determine the order in which different shipments would divert from the waterway as a result of lock congestion. The logistics total cost models are formulated to explain mode choice as a function of transportation rates, capital carrying costs, and storage costs. The least costly mode of transportation minimizes the sum of transportation rates and inventory costs. Inventory costs are a function of product value, interest rates (cost of capital), and speed, shipment size and stockpile requirements for each mode. Seven logistics cost models were developed to assess the relative impacts of lock congestion upon barge rates and inventory holding costs. The models range in complexity from analyses of transportation rate differentials to incorporating differences in inventory holding costs between barge and other transportation alternatives.

The logistics cost models are specified in Exhibit 1. Models 1, 2, and 3 compare the impact of lock congestion upon waterway shipper logistics costs to the costs of alternative modes of transportation. Model 1 predicts mode choice based on transportation rate differentials. Model 2 incorporates in-transit inventory holding costs in addition to linehaul rate differentials. Model 3 includes differences in the holding costs of inventory stockpiles for barge and other modes of transportation.

Models 4, 5, 6, and 7 express the impact of lock congestion upon shipper logistics costs in hours per ton of delay necessary to divert the shipment to alternative modes of transportation. The threshold level of lock congestion necessary to induce diversion is computed by dividing dollars per ton by dollars per ton hour. In Models 4 and 5 the denominator represents the delay cost per hour for a barge tow and in-transit inventory holding costs. In Models 6 and 7 the denominator includes the delay cost for the tow and in-transit inventory plus any additional inventory stockpile holding costs.

The critical inputs necessary to operationalize these models are: (1) annual tonnage for each commodity movement; (2) time between shipments; (3) inventory carrying costs; (4) shipment size; (5) insurance, loss and damage, and miscellaneous expenses; (6) expected transit time by mode; (7) average inventory stockpile levels for barge, with and without lock delay, and for alternative modes of transportation; and (8) total linehaul transportation rates and transfer charges for barges and alternative modes of transportation.[3]

A sample of 96 coal, 103 petrochemical, and 164 grain barge movements through Lock and Dam No. 26 at Alton, Illinois was obtained from the Upper Mississippi River Basin Commission (UMRBC). Lock No. 26 was selected because it is heavily utilized and shippers had experienced 40 to 50 hour delays at this facility. The UMRBC barge movement data contained the following information: (1) date code; (2) barge number; (3) linehaul rate; (4) origin dock code; and (5) destination dock code. Shippers and receivers were identified by the location of each origin and destination dock.

A letter was sent to the senior transportation or purchasing officer of 17 coal, 23 petrochemical and 15 grain companies represented in the sample. The companies were requested to furnish data for the eight inputs into the logistics cost models for each barge shipment.[4] Shippers were also requested to indicate the

LOGISTICS COST MODELS UTILIZED TO ASSESS THE IMPACT OF LOCK CONGESTION UPON WATERWAY SHIPPERS

MODEL 1: $Xdelay_1 = R_A - R_B$.

MODEL 2: $Xdelay_2 = R_A - R_B + Y^* (Time_A - Time_B)$.

MODEL 3: $Xdelay_3 = R_A - R_B + Y^* \left(Time_A - Time_B + \frac{Q_A - Q_B}{2^*DU}\right)$.

MODEL 4: $Ydelay_1 = \frac{Xdelay_1}{Y + (T/C)}$.

MODEL 5: $Ydelay_2 = \frac{Xdelay_3}{Y + (T/C)}$.

MODEL 6: $Ydelay_3 = \frac{Xdelay_1}{Y + (T/C) + (dI/dD)}$.

MODEL 7: $Ydelay_4 = \frac{Xdelay_3}{Y + (T/C) + (dI/dD}$.

The variables of these models are defined as:

R_A = Transportation rate for the least cost alternative mode ($/Ton);
R_B = Transportation rate for waterway transport ($/Ton);
Y = Interest rate per day times commodity value per ton ($/Ton);
$Time_i$ = Transit time by mode i,i = A,B (Days);
Q_i = Shipment size by mode i,i = A,B (Tons);
DU = Daily rate of commodity usage (Tons/Day);
T/C = Hourly cost of towboat and barges ($/Ton/Hour);
dI/dD = Change in on-site inventory given a one unit change in lock delay;
$Xdelay_i$ = Delay costs in dollars per ton for model i; and
$Ydelay_i$ = Delay measured in hours per ton for model i + 3.

EXHIBIT 1

effects of lock congestion upon inventory stockpiles and other shipment characteristics. A total of 11 coal, 14 petrochemical and 9 grain shippers participated in the research. Shipment characteristics were obtained for 85 coal, 47 petrochemical and 101 grain barge movements.

2. Analysis:

The percentage of coal, petrochemical and grain participants who furnished shipment characteristics is shown in Exhibit 2. The response rates indicate the percentage of participants who were able to supply data for the seven logistics components. Most of the firms and/or respondents participating in the research expressed unfamiliarity with rail-related inventory characteristics. For example, over one-half of the public utilities participating in the research did not have any rail service. Rail was not regarded by these respondents as a practical transportation alternative. Respondents were also generally unable to identify differences in insurance, loss and damage and miscellaneous expenses attributable to barge or rail transportation.

The results of the field research indicate that lock congestion had a relatively insignificant effect upon inventory stockpiles. Only 12 percent of the respondents indicated that inventories would increase in response to high levels of lock congestion (48 hour delay). The most frequent response from all categories and sizes of shippers was that high levels of lock congestion had no effect on inventory stockpiles. None of the respondents indicated that shipment size changed in response to lock congestion. Shipment frequency was changed, how-

LOGISTICS COMPONENT DATA FIELD RESEARCH

Component	Response Rate (percent) Coal	Petrochemicals	Grain
1. Annual tonnage	100	100	100
2. Time Between Shipments	73	86	78
3. Inventory Carrying Costs	64	29	11
4. Shipment Size-Tons:			
Barge	73	100	89
Rail	36	29	11
5. Insurance, Loss & Damage, and Miscellaneous Expenses:			
Barge	27	7	11
Rail	9	7	11
6. Expected Transit Time:			
Barge	82	79	56
Rail	18	29	22
7. Average Inventory Stockpile Level:			
Barge			
(A) No Lock Delay	100	79	44
(B) 48 Hour Lock Delay	82	79	44
Rail	27	21	0

EXHIBIT 2

ever, to reflect increased transit time attributable to lock delay. Shippers' response to lock congestion was to advance the date of shipment to reflect increased transit time, however, the long term frequency of shipment was not modified.

The character and degree of shipper responses were variable, ranging from qualitative assessments to detailed empirical data. After the primary data was reviewed for accuracy, the final data base consisted of 85 coal, 63 grain and 38 petrochemical movements. Missing data for barge and alternative mode shipment characteristics was obtained from secondary sources. Inventory carrying cost was computed on a twelve percent annual rate of interest and delivered prices of each product. Transit time was estimated as a function of length of haul.[5]

The impact of lock delay upon barge rates was estimated as a function of hourly tow operating costs.[6] Waterway operators were assumed to pass all increased costs from lock delay to shippers. The validity of this assumption rests upon the cost-based nature of contract rates in a competitive industry. The majority of waterway coal, petrochemicals and grain commerce moves under contract rates. Operators have responded to sustained levels of lock delay by including lock congestion costs in the contract rate or have adopted surcharges wherein shippers are billed for the actual amount of time a tow is delayed at a congested lock. The impact of a 48 hour lock delay upon barge rates is proportional to transit time without lock congestion. If a tow moves from St. Paul to New Orleans in 15 days, a 48 hour (two day) lock delay at Alton, Illinois would increase the barge rate by 2/15 or 13 percent, less any potential fuel savings while the tow awaits lockage.

The shipment characteristics of each barge movement and alternative mode of transportation were entered into the seven logistics cost models in Exhibit 1. The level of lock delay required to divert each barge movement from the waterway was computed. An ordered list of 186 barge movements that were diverted by lock congestion was compiled for each logistics total cost model. For example, Model Number 1 sequentially diverted water movements whenever the sum of the barge rate plus delay costs exceeded the sum of the barge rate plus delay costs exceeded the rail rate. Model Number 2 sequentially diverted movements whenever the sum of the barge rate plus delay and in-transit inventory costs exceeded the sum of the rail rate plus in-transit inventory costs.

Rank order correlations between the ordered lists of movement diversions from each model were computed. Table 1 indicates the rank order correlations between the two groups of models which have homogeneous outputs and are directly comparable. Models 1, 2 and 3 estimate waterway diversion in response to lock congestion costs expressed in dollars per ton. Models 4, 5, 6 and 7 estimate waterway diversion expressed in hours of delay per ton. The first subgroup of models had correlation coefficients of .9756 or greater, indicating that the model outputs were very similar. The correlation coefficient .9984 between Models 1 and 2 indicates that the impact of lock congestion upon in-transit inventory carrying costs does not affect waterway diversion compared to changes in linehaul rates. The correlation coefficient for Model 3, .9756, reflects the relatively insignificant influence of lock congestion upon in-transit and inventory stockpile holding costs compared to changes in line-haul rates.

The correlation coefficients for Models 4, 5, 6 and 7 were statistically significant at the .0001 level and were greater than .9643, indicating that the models generated very similar results. Since Models 4 and 5 did not include the effects of inventory safety stock increases in response to congestion, the high correlation coefficients in Table 1 between Models 4, 5, 6 and 7 suggest that inventory stockpile holding costs are not influenced by lock congestion.

The correlation coefficients between the ordered lists of diversions for each logistics total cost model were computed for coal, petrochemicals and grain. The correlation coefficients between the least and most complex models, with respect to inclusion of transportation rate differentials, in-transit and inventory stockpile holding costs, are shown in Table 2. Only petrochemicals did not reflect uniformly high correlation coefficients due to the wide range of product values within this commodity group and transportation rate structures for hazardous commodities. Further disaggregation of petrochemicals is necessary to separate distinct commodity subgroups with respect to transportation cost characteristics and product values. Otherwise there are no significant differences between the correlation coefficients in Tables 1 and 2.

The correlation coefficients in Tables 1 and 2 indicate that non-transportation

TABLE 1

CORRELATION COEFFICIENTS BETWEEN LOGISTICS TOTAL COST MODEL SUBGROUPS — ALL COMMODITIES

	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7
MODEL 1	1.0000 (0) P=*****	0.9984 (186) P=0.000	0.9756 (186) P=0.000				
MODEL 2	0.9984 (186) P=0.000	1.0000 (0) P=*****	0.9789 (186) P=0.000				
MODEL 3	0.9756 (186) P=0.000	0.9789 (186) P=0.000	1.0000 (0) P=*****				
MODEL 4				1.0000 (0) P=*****	0.9788 (186) P=0.000	0.9887 (186) P=0.000	0.9643 (186) P=0.000
MODEL 5				0.9788 (186) P=0.000	1.0000 (0) P=*****	0.9751 (186) P=0.000	0.9915 (186) P=0.000
MODEL 6				0.9887 (186) P=0.000	0.9751 (186) P=0.000	1.0000 (0) P=*****	0.9795 (186) P=0.000
MODEL 7				0.9643 (186) P=0.000	0.9915 (186) P=0.000	0.9795 (186) P=0.000	1.0000 (0) P=*****

(COEFFICIENT / (CASES) / SIGNIFICANCE)

TABLE 2

CORRELATION COEFFICIENTS BETWEEN LOGISTICS TOTAL COST MODEL SUBGROUPS — COAL, PETROCHEMICALS, AND GRAIN

	COAL	PETROCHEMICALS	GRAIN
MODEL 1: MODEL 3	.9993 (83) p = 0.000	.9939 (40) p = 0.000	.9975 (63) p = 0.000
MODEL 4: MODEL 6	.9934 (83) p = 0.000	.9579 (40) p = 0.000	1.0000 (63) p = 0.000
MODEL 4: MODEL 7	.9911 (83) p = 0.000	.8858 (40) p = 0.000	.9975 (63) p = 0.000

(COEFFICIENT/ (CASES)/ SIGNIFICANCE)

logistics costs for coal, grain and to a lesser extent petrochemicals are not appreciably affected by lock congestion. The relatively high correlation coefficients indicate that the primary impact of lock congestion is upon linehaul transportation costs and rates. Lock congestion will result in waterway diversion only when the level of delay increases shippers' linehaul costs of barge transportation above the costs of alternative transportation modes.

The correlation coefficients between the ordered lists of diverted movements from different logistics total cost models indicate the relationship between lock congestion and barge rates. As barge rates change in proportion to increased lock congestion shippers incur higher transportation costs. The logistics total cost models hypothesize that shippers will absorb lock delay costs based almost entirely on transportation rate differentials. The extent to which shippers absorb lock delay in excess of transportation rate differentials reflects their degree of captivity to the waterway and ability to pay congestion tolls or user fees.

The correlation coefficients in Table 1 were reflected in telephone interviews with respondents. Shippers indicated that lock congestion has virtually no impact on inventory stockpiles compared to other variables affecting supply and demand for coal, petrochemicals and grain. Shippers emphasized that the only important impact of lock congestion was upon linehaul rates.

Shippers indicated that they did not respond to lock congestion in the short-run by re-optimizing distribution systems. Some barge trading occurred but this was not usually related to lock congestion. The only impact of lock congestion upon inventories appears to be under conditions of extreme variability of delay. Shippers indicated that very high levels of lock congestion and/or variability of delay could effect diversion to other modes or stimulate barge trading.

Shippers could not quantify the threshold levels of lock congestion or variability of delay that would result in waterway diversion. In general, variability of lock delay was not perceived as a significant problem except for small shippers. It appeared that in the short-run, extreme levels of lock delay that would stimulate diversion to other modes were synonomous with lock closures. The levels of delay experienced at Lock No. 26 were indicated to be insignificant in the short-run due to the location and specialization of waterway facilities and interrelated production-distribution systems. Unless waterway operators could reduce delay costs associated with lock congestion, shippers only short-run alternative was to pay higher rates.

IV. IMPLICATIONS FOR USER FEES AND CONGESTION TOLLS:

The implications that can be drawn from the research are limited to the short-run.[7] The long-run responses of shippers to lock congestion can only be determined by analysis of the total logistics costs of alternatives to waterway transportation. This is the approach utilized in models of mode choice. However, there is little data on shipper responses to lock congestion in the long-run with regard to logistics system alternatives. Shippers cannot normally prescribe long-run responses to lock congestion in a manner which is conducive to traditional mode choice analysis. Shipper responses include multiple considerations that are not readily quantifiable such as shipping requirements, facility location, marketing patterns, multi-mode use, and regulatory constraints. These responses are not readily aggregated and incorporated into traditional analyses of mode choice and lock congestion.[8]

An additional problem in ascertaining shippers' long-run responses to lock congestion is that relatively large and sustained levels of lock delay are a recent phenomenon. As a result, the long-run impacts and shipper alternatives to high and continuing levels of lock congestion are conjectural. Most shippers indicate that they would attempt to minimize increased costs associated with lock congestion, but are not able to articulate how their responses specifically relate to long-term financial objectives and constraints. For example, many shippers indicate that higher costs associated with lock congestion will restrict their market and/or necessitate capital investment to accommodate other modes of transportation. These are not necessarily feasible long-run responses. Therefore, the implications of long-run impacts of congestion tolls and user fees upon waterway shippers cannot be directly inferred from this research effort.

The most important implication of research with respect to congestion tolls is that (short-run) demand for waterway transportation appears to be considerably more inelastic than is generally supposed. The degree of short-run inelasticity is the result of two factors. First, the opportunity cost of specialized waterway facilities or locations that cannot be practicably served by other modes of transportation approaches zero. Second, the demand for transportation services is a derived demand and waterway related transportation costs normally constitute a small portion of the delivered price of commodities. For example, if commodity demand were unit elastic and waterway transportation comprised ten percent of delivered price (export grain), a ten percent increase in transportation costs would decrease commodity demand by only one percent, a quantity effect that is well within the normal month-to-month variation experienced by grain merchandisers.

The implication of the relatively inelastic short-run demand for waterway transportation is that congestion tolls designed to alleviate lock delay will have to be substantially higher than rate differentials between the waterway and alternative modes of transportation. There are historical precedents for the imposition of "congestion tolls" by the towing industry to recover delay costs incurred at heavily utilized locks. Towing industry congestion surcharges in the range of ten percent cost increase noted above appeared to have a negligible effect upon shippers. Towing industry surcharges of this magnitude reflect very high values of demand, which is the essence of a congestion toll.

The use of congestion tolls, rather than user fees, to pay for capital construction costs on the inland waterways has both a theoretical and practical justification. The rationale for congestion tolls is that congestion reflects a need for capacity expansion. The costs of expansion constitute the difference between short-run and long-run marginal costs at a fixed capacity facility. Each user of a facility should pay short-run marginal costs, essentially operations and maintenance expenditures, and capital costs should be distributed among users based on demand considerations. Peak users would pay a fee which exceeds long-run marginal costs of providing additional capacity, while off-peak users would pay a lower fee. If the level of off-peak utilization was less than facility capacity, peak users would be assessed the entire costs of constructing new capacity. With a non-zero elasticity of supply, both peak and off-peak users would contribute to the costs of providing additional capacity, although off-peak users would bear a smaller portion of the costs than peak users.

Although most congested locks do not exhibit extreme peak and off-peak periods of utilization during the navigation season, this distinction between users is useful in developing a practical rationale for the imposition of congestion tolls. Under current pricing policies, neither peak nor off-peak waterway users pay the full short-run marginal costs of providing the waterway system. The result of underpricing of waterway services is that the system is over-utilized with respect to marginal cost pricing of the waterway system. This has the effect of masking differences in the elasticity of demand between shippers who are located at different proximities to the waterway.

Past research indicates that the elasticity of demand for barge transportation is sensitive to the proximity of shippers to the waterway.[10] Shippers or receivers located on the waterway can be regarded as relatively water captive. Those shippers not located directly upon the waterway incur additional water-related shipping costs. The impact of this cost differential is that the elasticity of demand for waterway services generally increases as distance from the waterway increases. Because shippers (or receivers) do not pay the short-run marginal costs of maintaining the waterway, they are able to absorb short-run increases in costs as a result of lock congestion. Shipper behavior may erroneously be interpreted as evidence that structural improvements are justified by demand (absorption of delay costs) for a congested lock, when the waterway system is underpriced with respect to short-run marginal costs of operating the system and congestion costs to captive users. The estimated level of delay at congested facilities will be overstated in the long-run. This will result from the fact that shippers (or receivers) not directly located on the waterway will shift to alternative modes in the long-run at a much faster rate than is evidenced by short-run shipping patterns at a congested facility, due to differences in demand elasticities.

The imposition of a congestion toll will have the effect of increasing shipping costs above the level that includes only average congestion costs. If congestion tolls were implemented as an on-going policy to manage the waterways and pay for new construction, there would be a tendency on the part of shippers and receivers to reveal their long-run mode choice decisions based on efficient waterway pricing. Experience at Lock No. 26 and Gallipolis Locks indicates that shippers and receivers are willing to incur rather significant short-run congestion costs. Part of the absorption of short-run congestion costs reflects ability to pay the long-run marginal costs of system operation and maintenance. The imposition of congestion tolls under these circumstances would partially offset the effects of the lack of user fees by revealing shippers' true demands for waterway services.

This would appear to be the primary long-run impact of a congestion toll. Shippers or receivers who are unwilling to bear the short-run costs associated with a congestion toll would utilize alternatives to the waterway, thereby alleviating congestion. Other than the loss of marginal shippers, the impact of a congestion toll on shipment patterns is likely to be insignificant. This is precisely the result that a short-run congestion toll is designed to achieve. By forcing shippers to reanalyze their demand for waterway services relative to other alternatives, a congestion toll will lead to more efficient utilization and investment in waterway facilities.

V. CONCLUSIONS:

Limitations in short-run shipper responses to lock congestion facilitate the imposition of a congestion toll with relatively modest impacts. By properly pricing waterway facilities, a congestion toll would stimulate shippers to more accurately reveal their long-run ability to pay for both operations and maintenance and capital costs of the waterway system. The imposition of a user fee to recover operations and maintenance costs is reasonable, although as an ad hoc mechanism to recover existing capital costs it will overprice waterway services and is a suboptimal pricing scheme. A congestion toll would not be burdensome to shippers and could be designed to fund future capital costs on the waterway system.

FOOTNOTES

1 Traditionally transportation rate differentials on future traffic in excess of lock capacity have been the major source of benefits. More contemporary waterway analyses have focused on delay savings to projected growth of existing traffic. See for example, U.S. Army Corps of Engineers, Locks And Dams No. 26 (Replacement): Supplemental Economic Data, Part I (St. Louis, Missouri; January 1977) pp. 7-1-7-12; and Gallipolis L & D Replacement, Ohio River Phase 1, Advanced Engineering and Design Study General Design Memorandum (Huntington, West Virginia; November 1980).

2 James G. Crew and Kevin H. Horn, "Logistics Total Cost Prescriptions: Do the Theoretical Results Necessarily Conform with Reality?", Proceedings of the Transportation Research Forum, Volume XXI, Number I (Oxford, Indiana; The Richard B. Cross Company) 1980, pp. 325-326.

3 Not all of these variables were directly entered into the logistics cost models. For example, insurance, loss and damage and miscellaneous expenses incurred by the shipper were added to the linehaul transportation rate component of the models.

4 To minimize shipper concerns about disclosure of confidential data the barge rate for each sample movement was specified. Shippers were asked to review the rates we obtained from the Upper Mississippi River Basin Commission for accuracy.

5 R.L. Banks & Associates, Inc., Rail User Access Cost Study: A Report To Upper Mississippi River Basin Commission (Washington, D.C.; July, 1981).

6 U.S. Army Corps of Engineers, "Estimated Operating Costs of Towboats on the Mississippi/Gulf Waterway System," (Fort Belvoir Virginia; Institute for Water Resources) January, 1981.

7 Because of the long life of capital assets in the waterway industry, lead times in construction, etc., the short-run can easily be a period of five to ten years for waterway shippers.

8 This is a standard problem in the development of mode choice models or transportation demand analysis. While models exist that incorporate some of these issues, no model has been

designed that incorporates the full range of these responses.

9 O. E. Williamson, "Peak Load Pricing and Optimal Capacity," American Economic Review, Volume 56 (September, 1966) pp. 810-827.

10 U.S. Army Corps of Engineers, "The Demand For Water Transportation: Application of Discriminant Analysis to Commodities Shipped by Barge and Competing Modes in Ohio River and Arkansas River Areas," (Fort Belvoir, Virginia; Institute for Water Resources) Research Report 80-R2, August, 1980.