The Economic Impacts of Lock Delays: Estimation of Logistics Cost Impacts

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A review is presented of survey results from interviews with 107 shippers and waterway operators who use Lock and Dam 26 on the Mississippi River, Gallipolis Lock and Dam on the Ohio River, or both. Both locks experience significant congestion-related delays when in use. The focus of the survey was to elicit responses that indicate the ways that delays affect (a) the economic costs of shippers and operators, and (b) the adaptive responses of managers in both kinds of enterprises. The survey results suggest that the variability of delays may have more profound economic costs than average delays. Therefore, investigation of inventory-related methodologies appears warranted.

Ever since the economic analysis of alternatives to expanding the capacity and replacing Lock and Dam 26 on the Mississippi River was presented in the 1960s, a continuing debate has occurred. The applicability of congestion tolls—to correct some of the externally imposed waiting-time costs and to seek an efficient equilibrium use of a congested facility—has been offered by several researchers including Lave and DeSalvo *(1)*, Hanke and Davis *(2)*, and Shabman *(3)*. The proper analysis to obtain an efficient congestion toll goes along with the policy arguments by Howe et al. *(4)*, and Case and Lave *(5)*. The debate about an effective and efficient methodology for estimating the relationship between delays (from any source including congestion) and the economic demand for barge transport continues in one direction.

It is the contention of this paper that the methodology used by the U.S. Army Corps of Engineers (Corps), which primarily relies on transport cost differentials between barge and alternative modes, should consider the time-costs of delay by including the impacts of the variability of delays on inventory costs of shippers. In the current Corps methodology, delays add cost to barge transport by a linear increase of tow-operator costs times the expected delay time. If the expected delay time at a given lock is 8 hr, the added costs of each tow transiting the lock would be increased by 8 times the average hourly tow-operating cost. These costs are added to the barge-transporting costs for each shipment using the lock and compared to the shippers cost of transporting the shipment by the next more expensive mode of transport, generally rail. If the cost of shipping by barge exceeds the cost of shipping by the lowest cost alternative, the shipment is diverted to the lowest cost mode. Therefore, the existing methodology to evaluate the economic impact of delay fundamentally rests on cost differences derived from expected delay. The added costs are assumed to be passed through to shippers. If these increases reduce the barge shippers' cost savings over the next best alternative to zero, it is assumed that the shipper diverts to the least costly alternative mode. The methodology allows for the increased inventory-carrying cost during transit (using expected delays) to be included in the analysis. If towing firms pass only expected delay costs to the shipper, and if there are no additional diseconomies to the shipper, this methodology should provide an accurate assessment of the economic impact of delay. Benefits that measure the expected delay would equal the value of the delay cost reductions passed along by the towing company, plus the net savings available to shippers who would otherwise divert to another mode.

EXISTING METHOD

Each lock can be characterized by its capacity, which is determined by lock dimensions, and the associated maximum tow size and the amount of time required to transit the lock. Every lock can therefore transit a maximum upperbound of tows in any given time interval. If tow arrival is random, delays will occur as a result of queueing at traffic levels lower than maximum capacity. Assuming a Poisson arrival rate and a uniform pricing rate, a hyperbolic delay function will result. The delay function will increase monotonically as capacity is approached. The existing project with Capacity C_1 and Delay Function D_1, as well as a potential expansion project with Capacity C_2 and Delay Function D_2 are shown in Figure 1. The delay functions can be converted into supply (average cost) functions to determine the equilibrium level of traffic that

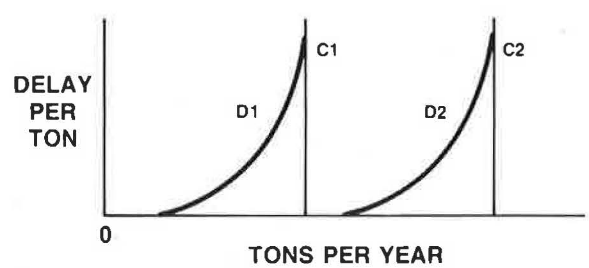

FIGURE 1 Lock delay functions.

would transit the lock and the benefits that would be attributable to a facility that increases capacity. The demand for barge transportation at the lock determines equilibrium traffic levels and resulting benefits given to the supply functions. In short, the demand function is assumed to represent the savings available to each shipper who would use the lock; that is, the net transport cost (including expected delays) by waterway subtracted from the net transport cost (including expected delay) for the next higher cost transport mode. Therefore, the demand function shown in Figure 2 reflects the cumulative tonnage that could transit the lock arrayed from shipments with the highest savings to shipments with the lowest

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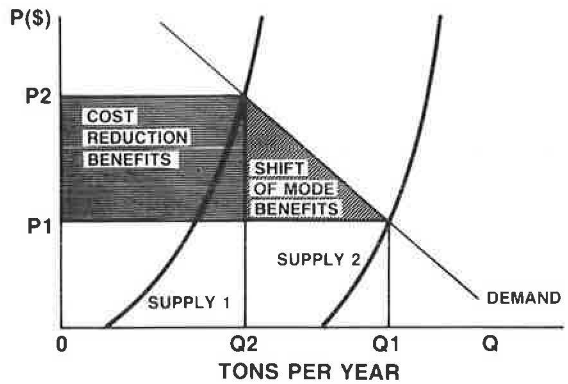

FIGURE 2 Benefits from increase in capacity.

savings, and the supply curves represent the effects of the delay function shown in Figure 1. The nonproject equilibrium traffic is OQ_2, with delay cost OP_2. Measures that would reduce delay costs to OP_1 would generate cost reduction benefits, $Q_2 \times (P_2 - P_1)$, and shift of mode benefits, $(P_2 - P_1) \times (Q_1 - Q_2)/2$. In a general form this model can be written as:

$$D_b = f([R_a - R_b] + [ITC_a - ITC_b]) \quad (1)$$

where

D_b = quantity demanded for shipment by barge,
$R_{a,b}$ = transport rate of alternative and barge, and
$ITC_{a,b}$ = carrying costs during transit by alternative and by barge.

In this model carrying costs during transit and barge-transport costs are directly affected by delay. The critical assumption is that both impacts can be estimated from changes in expected delay.

OTHER MODELS OF THE ECONOMIC IMPACT OF DELAY

Inventory theoretic models based on the path-breaking work of Baumol *(6)* suggest that delay could provide a stronger economic impact on shippers via the influence of delay on increased inventory levels, in addition to the added costs of barge operation and carrying costs during transit. Baumol's model of transport demand includes (a) inventory levels required to satisfy the economic penalties of stock out, (b) ordering costs, and (c) costs of on-site inventory storage and management. A cost minimization policy by shippers would consider these costs, in addition to costs during the transport leg of the logistics process. For the purpose of this discussion, the Baumol model can be written as follows:

$$D_b = f[(R_a - R_b) + (ITC_a - ITC_b) + (O_a - O_b) + \text{stock out penalty} + (ISC_a - ISC_b)] \quad (2)$$

where O_a and O_b are order costs by alternative mode and barge, and the stock-out penalty is a nonlinear function of the probability of stock out; and ISC_a and ISC_b are the shippers on-site costs for storage, pilferage, inventory management, and so on.

In Equation 2, all of the terms are influenced by delay except order costs. The model is turned into a logistics cost model as follows:

$$\text{Cost} = Q_b[(R_a - R_b) + (ITC_a - ITC_b) + (O_a - O_b) + \text{stock out penalty} + (ISC_a - ISC_b)] \quad (3)$$

Cost minimization behavior would result in the combination of mode selection, shipment size, and on-site inventory policies that produce the lowest total logistics cost. Delays could perturb every term in the cost function.

Benefits from reduction in delay would be equal to savings because of the reduction of inventory required to avoid or reduce stock-out impacts, reductions in the cost of inventory storage and maintenance resulting from reduced delay, and reductions in order costs, in addition to the reduction in towing costs and carrying costs during transit.

A fairly contentious debate between proponents of each methodology has evolved. [See Crew and Horn *(7)*, and Nason and Kullmun *(8)*.] A vigorous discussion is desirable, because implementation of the inventory theoretic models would increase study costs and could delay study schedules. It can also be argued that the economic context of shippers using waterway transportation is different from shippers using other transport models. Barge shippers move large loads of bulk materials long distances. The relatively low value of the product shipped, low spoilage rate during transit, and low on-site storage costs all reduce the importance of inventory costs as compared to high value, high spoilage risk, as well as expensive inventory storage and inventory management costs typical of many manufactured products that normally use other modes.

Because the choice of methodologies has a potentially significant study cost and study-schedule impact, the choice of a preferred methodology should be based on careful analysis of the risks, costs, and benefits of the competing methodologies. Therefore the debate is useful to the Corps and to the various shipper and towing industry groups whose economic welfare may be affected by the choice of methods. Basically, the proponents of the inventory theoretic-logistics cost methodologies argue that important potential economic benefits from reduced delays are not included by the traditional method. The opposing arguments are that logistics cost-based benefits are relatively small and that there is limited statistical evidence of significant differences in benefits due to properly estimated logistic cost models as compared to the traditional model. Further they argue that the cost of obtaining good-quality data for the logistics model are likely to be substantially higher than the traditional model.

A recent study based on interviews of 75 shippers and 33 towing companies using Lock and Dam 26 and Gallipolis Lock has been completed by Brown Associates for the U.S. Army Engineers Institute for Water Resources, Fort Belvoir, Virginia (1984). The sample was drawn from the shippers and carriers who shipped or hauled a substantial fraction of the traffic using these locks. The following section summarizes the major findings from the interviews.

STUDY RESULTS

The interviews were designed to reach decision makers of shipping and barge companies and to elicit both data and opinion about the economic impacts of lock delays over a period of years. The following key points came from the interviews:

1. Barge operators attempt to pass forward the expected delay costs, subject to market conditions. At the time of the interviews

(summer or fall of 1984) most barge operators were operating in precarious financial circumstances following a sharp decline in traffic in recent years due to the business cycle. In many cases, it is not possible to pass delay costs along to shippers.

2. Barge operators and shippers have responded to large delays with revised scheduling of shipments and equipment, increased barge loading, increased back haul, and several other measures that have the effect of moderating the economic penalties of delay.

3. Shippers apparently respond both to expected delays and to the variation of delay time. Variation of delay does affect on-site inventory levels and associated costs.

4. Both barge operators and shippers are aware of considerable variation in delay times.

5. Barge operators imply that variance in delay time can affect their equipment and labor utilization.

6. An adaptive response by both shippers and barge operators acts to mitigate the economic costs of delay and reduce total delay. The precise adaptive response is not obvious from the information gathered in the survey.

A more thorough analysis and report on these interviews will be prepared and published later.

PROPOSED RESEARCH

At this time, two additional tasks are underway. First, data on delays in the national lock performance monitoring system (PMS) data base for all Corps-operated locks are being analyzed to determine the extent and statistical quality of the variation in delays that have been experienced across the inland waterway system. If the data support a finding that there is a considerable variability in delay, an incursion into logistics models may be warranted.

A move to test various logistics models with emphasis on the impact of variability of delay on shipper inventory levels, inventory storage, and management costs would be a logical step. The strategy would seek the simplest forms of adequate logistics models.

Second, in anticipation of a move in this general direction, research on matching inventory models from the operations research to the primary logistics characteristics of (a) utilities (the primary coal user), (b) primary metals manufacturing and distribution, (c) chemical manufacturers, and (d) grain-marketing and grain-processing firms are underway. This screening process will provide an improved basis for predicting costs of additional research and testing, which would be needed to develop (a) a practical methodology that includes logistics costs, and (b) better evidence on the data bases that would be required to implement the methodology.

Corps studies and research have generally shrugged off logistics models when they are based on expected delays. The evidence is that an approach based on expected delays would generate limited additional information on the economic aspects of delays over the traditional model. However, a shift to emphasize variability of delay would appear to add considerable information on economic impacts. Whether the added benefits exceed the added costs will depend on actual experience in Corps studies.

SUMMARY

Questionnaire responses from shippers ($N = 74$) in the study are summarized as follows:

- Main reason for shipping by selected mode = cost (84 to 99 percent).
- Anticipate shift of mode (5 percent).
- Estimate of future traffic: no change (75 to 77 percent), up to 10 percent increase (8 to 10 percent), 10 to 20 percent increase (7 to 9 percent), and more than 20 percent increase (4 to 6 percent).
- If waterway were not available: shift modes (64 percent), shift O-D (27 percent), go out of business (6 percent), and other (4 percent).
- Locks that cause congestion delays: Lock and Dam 26 (65 percent), Gallipolis (27 percent), and other locks (Lock and Dam 51 and 52, Lock and Dam 7 and 8, and others) (39 percent).
- Importance of level or variability in delays: variability (49 percent), level (28 percent), and same (9 percent).
- Sources of data on delays: communication with carrier (71 percent), grapevine (36 percent), Corps data (28 percent), and transit time and delay reports (15 percent).
- Steps taken to minimize impact of delay: adjust production schedule to reflect delay (65 percent), divert to other modes (41 percent), and divert to other markets (30 percent).

The results of carrier interviews ($N = 33$) are summarized as follows:

- Where delays are experienced: Lock and Dam 26 (73 percent carriers and 65 percent shippers), Gallipolis (58 percent carriers and 27 percent shippers), and other (24 percent carriers and 39 percent shippers).
- Average length of delay (1983): high (31 percent at Lock and Dam 26 for 58.4 hr and 22 percent at Gallipolis for 37.3 hr), medium (28 percent at Lock and Dam 26 for 15.0 hr and 3 percent at Gallipolis for 12.0 hr), low (33 percent at Lock and Dam 26 for 2.5 hr and 21 percent at Gallipolis for 1.4 hr), and an overall average delay of 14.5 hr at Lock and Dam 26 and 5.8 hr at Gallipolis.
- Locks causing congestion: Lock and Dam 26 (73 percent), Gallipolis (58 percent), and other (24 percent).
- Anticipated trends: more backhaul (42 percent), more contract rates (37 percent), and more barge trading (30 percent).
- Importance of level of delay or variability: level (49 percent), variability (36 percent), and both (15 percent).
- Accuracy of prediction: 69 percent highly confident on level of delay, and 39 percent highly confident on variability.
- Importance of lock congestion to operation: 64 percent very important or important.
- Sources of data on congestion delays: grapevine (94 percent), communication with carriers (90 percent), transit delay report (79 percent), corps lock delay data (7 percent), and vessel logs (5 percent).
- Impact of lock congestion on operations: fuel consumption and tow speed (94 percent), tow scheduling (79 percent), transit time (52 percent), and equipment and labor utilization (46 percent).
- Influence of lock congestion on mode choice: linehaul rates (70 percent), other costs (36 percent), and diversion to other modes (36 percent).
- Method for incorporating lock congestion into long-term contract rates: inclusion in base rate (94 percent), and absorption by towing company (94 percent).
- Steps taken to minimize lock congestion impacts: absorbed costs (88 percent), changed schedules (73 percent), increased rates (70 percent), increased tow size (36 percent), increased barge

loading (15 percent), changed fleeting location (15 percent), increased backhaul (12 percent), and other (8 percent).

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