being the striking versus the struck vessel in a collision, and the frequencies of rammings and groundings can be intrinsically and analytically related.

Although data have often been said to indicate that course angles are isotropically distributed, it does not follow that collision angles are also isotropically distributed. What has been described as a 90^o impact is not normal incidence; 90^o simply describes the orientation of the striking ship. Because of the variation of relative velocity and collision energy with collision angle, a 90^o impact clearly does not necessarily represent the worst case.

The usefulness of the model discussed here derives largely from the appearance of the canonical variables (v_i). These variables essentially make it possible to exchange spatial information for time-related information, which is more readily available and less variable. That is, it is not necessary to specify a ship's location or course in a region but only to specify the time it spends in the region. Thus, the size of the region D^2 can be viewed as a measure of the imprecision or uncertainty about a ship's position.

The fundamental collision probability integral developed for the analysis of stochastic motion is also suitable for other modes of motion since the density function $\lambda(\theta_R)$ can be arbitrarily perturbed or restricted to reflect nonisotropic distributions of ship orientations in the global reference frame. Thus, specific situations such as ship crossings, meetings, and overtakings can be individually analyzed. However, such efforts to quantitatively predict and restrict future accident scenarios require additional assumptions.

Because all the model results appear in analytical form, the implications of perturbations of the input parameters to reflect excursions from known or existing situations or to explore the sensitivities of the predictions can be easily determined. In particular, the model easily lends itself to the investigation of transportation scenarios projected for specific sites and operations.

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Locks and Dam 26: A Dilemma in National Transportation Policy

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The issue of Locks and Dam 26 and its relation to the issue of waterway user charges represents a critical decision point in emerging national transportation policy. The history, operation, and deterioration of Locks and Dam 26 on the Mississippi River and its place as the legislative fulcrum by which to impose user charges on the waterway system are reviewed. Various types of user charges are defined, and their impacts are quantitatively explored. The relation of user charges to emerging national transportation policy and the current user charge legislation under congressional consideration are discussed. It is concluded that any user charge scheme should be initiated on a partial and monitored scale with respect to capital and operating cost recovery so that the feedback to the national multimodal transportation system can be studied and unstable patterns of use and investment do not result. The implications of rail-water rivalry with respect to modal equity are also considered.

To the casual observer, the U.S. Army Corps of Engineers' Henry T. Rainey Dam near Alton, Illinois, seems a most unlikely subject for a national controversy. This facility, commonly known as Locks and Dam 26, appears a rather ponderous and substantial expanse of iron and concrete spanning the Mississippi River, its passivity underscored by the constant activity of river traffic around it. Yet the structure is not passive but responds dynamically to a myriad of mechanical, geological, and hydrological forces that threaten its physical condition and efficiency. In turn, it is generating economic, political, and social pressures that have brought before the nation the question as to whether the public or its users shall pay for replacement and operation of the facility.

Locks and Dam 26 was authorized by the Rivers and Harbors Act of 1935 and placed in operation on May 1, 1938. The structure has two locks on the north bank of the river, a main lock 30 by 182 m (100 by 600 ft) long and an auxiliary lock 33 m (110 ft) wide by 109 m (360 ft) long. The dam consists of a gated spillway with three roller gates 24 m (80 ft) wide by 8 m (25 ft) high, and 30 tainter (adjustable flow) gates 12 m (40 ft) wide by 9 m (30 ft) high. The dam impounds a pool at a maximum elevation 127 m (419 ft) above sea level, which extends 64 km (38.5 miles) up the Mississippi River to Locks and Dam 25 and 129 km (80.1 miles) up the Illinois River to the LaGrange Lock and Dam (1).

Locks and Dam 26 is the penultimate facility of 27 locks and dams on the upper Mississippi River that create navigable, slack water pools for a total of 1079 km (669 miles), from the Upper St. Anthony Falls near Minneapolis to Locks and Dam 27 near Granite City, Illinois. Under the Rivers and Harbors Act, the Corps of Engineers was authorized to maintain a 2.7-m (9-ft) navigation channel depth between Minneapolis and the confluence of the Mississippi and Missouri rivers approximately 13 km (8 miles) downstream of

Locks and Dam 26. The Illinois River, which stretches from Lake Michigan at Chicago to its confluence with the Mississippi 24 km (15 miles) upstream from the facility, is similarly maintained at a 2.7-m channel depth.

The middle Mississippi (from the confluence of the Ohio River and the Mississippi to the mouth of the Missouri River) provides a 2.7-m-deep channel for access to and from the facility for the lower Mississippi and the Ohio River. The lower Mississippi has a channel depth authorization of 3.6 m (12 ft) but is presently maintained at that depth only from the Gulf of Mexico to Baton Rouge, Louisiana. Moreover, the strategic geographic position of Locks and Dam 26 is illustrated by the fact that it provides waterborne access and egress to over 21 states plus the Great Lakes and the Atlantic Ocean (2).

The facility at Alton enjoys an economic status commensurate with its geographic significance. In 1976, the facility handled more than 52 million Mg (57 million tons) of bulk commodities. Substantial amounts of grain, particularly corn and soybeans, move south through the facility to lower Mississippi ports for export and domestic markets. Nitrogen and phosphate fertilizers and petroleum move northward to farming areas and utilities. Thirty percent of total U.S. grain exports--over $4 billion--moved through the locks in 1976. The commodities and their 1976 amounts (3) are given below (1 Mg = 1.1 tons):

Commodity	Megagrams (000s)	Percentage of Total
Grain	27 702	53
Petroleum	6 409	12
Coal	4 700	9
Chemicals	4 751	9
Sand and gravel	674	1
Iron and steel	2 236	4
Miscellaneous	6 081	12
Total	52 553	100

Although these figures speak eloquently of the importance of the Alton dam, the same statistics illustrate its most severe shortcomings. Originally designed for a practical annual capacity of 37.7 million Mg (41.5 million tons), the barge traffic achieved that capacity in 1968 and has steadily increased since that time (4). The maximum capacity of the facility and when that capacity will be reached are open to question. Assuming an "infinite queue," use of switchboats, facility improvements, and improved traffic handling, estimates have ranged from 66 to 80 million Mg/year (73 to 88 million tons/year). According to Corps of Engineers projections, these levels may be achieved between 1980 and 1990 (5). A vivid illustration of the practical difference between effective and maximum capacity is provided by the fact that delay time per tow averaged approximately 8 h for both locks in 1976.

A second problem suffered by Locks and Dam 26 is its physical deterioration. The Corps has undertaken nine major repairs to the facility since its 1938 inception. These repairs were not attributable to navigational mishaps but to scouring, voiding, and design inadequacies (6).

A variety of solutions have been offered for the problems confronting Locks and Dam 26. Beyond maintaining the status quo, rehabilitation of the existing structure has been suggested. The rehabilitation option has not, however, been well received by Congress; both the House and the Senate have opted for replacement of the existing facility by a new locks and dam approximately 3 km (2 miles) downstream from the present facility.

Of critical importance in the economic struggle over Locks and Dam 26 is the interrelationship between two competing modes of transportation. The waterway interests maintain that the rail mode is attempting to arrogate potential future traffic to which the barge industry would rightfully fall heir. The railroads, on the other hand, maintain that such future traffic is an unjust enrichment of waterway interests because of the current, allegedly total, subsidization of the waterways by the federal government.

It is not the purpose of this paper to determine the proper successor to the riches of future traffic but to analyze the scenarios of commodity shipments through either improved or unimproved Locks and Dam 26, the magnitude and direction of traffic dimensions (if any), and the ultimate impact on both modes. Again, the existing facility has a maximum annual capacity of 66 million Mg (73 million tons). The capacity of a single 364-m (1200 ft) lock (as currently before Congress) has been estimated to be 78 million Mg (86 million tons). It should be noted, however, that such figures by themselves are of little use unless one considers the capacity of the waterway systems that serve the facility. If the constraint of the present facility is assumed to be reduced by the proposed replacement structure and existing constraint points remain constant, Locks and Dam 26 would be subject to a total traffic of almost 93 million Mg (102 million tons). By the year 2035, these capacities reach the levels of 98 and 174 million Mg (108 and 191 million tons) respectively. From these figures, it may be concluded that other constraint points will also become critically important in the future and that the question of traffic diversion caused by a new facility may in the near future become moot.

The U.S. Department of Transportation (DOT) has recently stated that a single 364-m (1200-ft) lock "will not cause significant diversion of existing rail traffic to the waterways" (7). It should be noted, however, that such a statement must be qualified by the fact that legislation now pending in Congress (H. R. 8309, Section 102C2) provides for an evaluation of the need for a second lock at the new facility. This evaluation will consider the impact of such an expansion on the railroads, but an erroneous projection could effect a diversion from rail to barge. Moreover, it could also be valid to note that the railroad industry has for the last 40 years suffered a steadily declining share of total intercity commodity megagram-kilometers--from 75 percent in 1929 to 23 percent in 1970 (8). Any adverse impact that a new Locks and Dam 26 may have on the railroads' modal share must be considered in this historical context.

Even if there is a dramatic increase in the capacity of a new Locks and Dam 26, it does not follow that such an expansion will benefit waterway operators at the expense of rail interests. In a recent study, four class I and II railroads with main-line trackage parallel to the Mississippi River and its tributaries were compared with barge lines throughout the country. In the period between 1946 and 1971, these railroads experienced a 76.2 percent increase in regulated commodities compared with an 18.6 percent increase among the other railroads. The barge lines enjoyed a 673.9 percent increase in the same period. It would appear that, whereas barge traffic shows a phenomenal increase, other market forces are at work that provide the railroads with competitive advantages (9).

USER CHARGES

The commentary above is a natural starting point from which to consider current policy and the legislative process. Current legislation proposes to tie Locks and Dam 26 to "complete recovery" of capital and operating costs on the system. Both the Senate and House bills differ dramatically in their level. The House bill calls for a return on diesel fuel of $0.02/L ($0.06/gal); Senate discussion, undecided at this point, has used numbers that range as high as $0.11/L ($0.42/gal). This indicates a need to look at user charge economics more closely. That will be accomplished by first defining the types of user charges:

1. A fuel tax per liter of tow diesel fuel consumed;
2. A megagram-kilometer fee linearly related to size and length of tow haul and possibly stratified by commodity type;
3. Segment tolls that are assessed on all individual links of the waterway structured as contiguous sections, are insensitive to traffic volumes, and are similar to a classic turnpike toll;
4. Congestion tolls levied at constraint or congestion points as a function of the level of congestion or traffic intensity at these various points; and
5. License fees, bulk fees levied annually on all towboats operating on the river (similar to a taxi medallion charge).

Although these measures have several impacts, it is best to deal initially with the quantitative impacts of some of these types of user charges by using the reach of the river that includes Locks and Dam 26 as the study area.

The river segment that runs from the confluence of the Illinois River to Locks and Dam 27 covers 53 km (32.7 miles). The current breakdown of commodity flow (1) is given below (1 Mg = 1.1 tons):

	Level of Traffic (thousands of megagrams)		
Year	Minimum	Likely	High
1977	–	52 727	–
1980	57 310	63 343	85 421
1985	63 179	77 999	112 699
1990	62 538	91 199	131 504
2000	63 090	115 010	172 020
2010	65 281	128 816	188 576
2020	68 291	144 614	207 120
2030	72 876	163 505	228 249
2035	75 575	174 300	241 568
2040	78 525	185 794	254 513

The calculation of the likely 1977 level of traffic is based on statistics available through September 1977.

The following quantitative aspects of user charges are based on annual commodity flows for 1977. The user charge levels and quantitative structures were derived from the work of Bronzini, Clark, and Strack (10):

1. For diesel fuel, costs to the operator (calculated in U.S. customary units) at $0.06, $0.12, and $0.40 are $0.06/$341 388, $0.12/$682 776, and $0.40/$2 275 920, which results in 6.6, 13.2, and 44.4 percent cost increases respectively to the towing industry. For a 100 percent recovery, a $0.05/L ($0.175/gal) tax is needed.
2. Based on length and size of haul for the segment under study, use of a tax of 0.27 and 0.55 mill/Mg·km (0.4 and 0.8 mill/ton-mile) increases the costs by 14.7 and 29.4 percent respectively and yields a recovery of $759 000 and $1.6 million respectively for system operation and maintenance.
3. Based on a segment toll concept, the upper Mississippi segment that includes this reach shows 50 percent recovery of operating and maintenance costs at 2.2 mills/Mg·km (3.2 mills/ton-mile) and 100 percent recovery at 2.5 mills/Mg·km (3.7 mills/ton-mile).

Although the impacts discussed above are monetarily the most visible readouts of the system, other very meaningful process impacts occur that are worthy of discussion and that could themselves cause real impacts on traffic and transportation systems distribution and costing throughout the entire multimodal and economic network. These include the following:

1. The fuel tax obviously yields a price increase that must be passed on to the consumer. Other literature implies that the potential for diversion to other modes is reasonably small unless the extreme of $0.11/L ($0.40/gal) is incurred. This tax, like other gasoline pump taxes, represents a direct relation to the energy status and policy of the nation and would have to be monitored carefully in light of these factors. To ensure economic stability, these taxes must not be subjected to unstable, highly time-sensitive swings in the pricing mechanism.
2. The megagram-kilometer charge is also a relatively stable charge mechanism, which implies that the increment will be passed on, at least in part, to the consumer. Again, recent simulation literature shows minimal modal-split diversion (10). The accounting and user charge mechanisms appear difficult to administer, based on origin-destination, common arrangements within tows, and other operating arrangements of tow makeup and dispersal.
3. The segment toll, although possibly sound in a microeconomic sense, is definitely a poor tool for in-place transportation systems because each segment is tolled a constant amount regardless of use to administer recovery and operation costs. This results in minimal use of the incentive and development portions of rivers and intermodal locations on the network. As a result, the capability of the waterways to sustain development of new markets and yield focal points for port, terminal, and industrial development is definitely minimized. This process of containment of waterway transportation resources and related multimodal development will only serve to retard regional economic development.
4. The congestion toll system has basic microeconomic appeal but also yields definite short-range stability to a developed transportation system. Although intended to bring about equilibrium of supply and demand, it is most certain to cause wild fluctuations in the use of modal components of the entire network. Although this may seem to serve as a modal diversion tool for the railroads, such a posture is not in the long-run interests of national transportation investment policies. Such an approach is simply too sensitive to time and facility capacity and creates seasonal regulation problems that result in potential oversupply or undersupply of capacity in terms of barges, rail cars, trucks, and so on. This system, although superficially appealing in a statistical sense, belies the true lump sum investment and capacity problems of a multiregional freight transportation system.
5. The licensing fee has properties similar to those of fuel and megagram-kilometer charges. However, its very nature requires that it be a yearly single fee charged per towboat. As such, it is not truly traffic dependent, and its inflexibility may result in overcharging or undercharging for facility operation and a potential reorientation of supply in towboat construction as waterway companies reverse their fleet investment process. It is appealing in its simplicity, but it is not the preferred charge process.

SUMMARY AND CONCLUSIONS

It is appropriate to attempt to synthesize the preceding historical, legislative, and quantitative discussion to structure the issues in a meaningful manner. In summary,

1. Is it appropriate to retard capacity development of one mode because of the financial difficulties and presumed inequities of another? The Regional Rail Reorganization Act of 1973 and the Rail Revitalization and Regulatory Reform Act of 1976 have created highly structured defense plans for bringing the railroads up to par. Obviously, this is an uphill fight, but a plan does exist and is in current implementation. If appropriate user charge conditions are met, to fail to recognize Locks and Dam 26 as the singular constraint on the system is technical ignorance, and not to improve it is to retard capacity stimulus where congestion is obvious. Locks and Dam 26 should be rebuilt in conjunction with a reasonable user charge program.

2. The preferred type of user charge is a head tax on diesel fuel. This tax is simple, is appropriately tied to other issues of national energy policy that affect the whole transportation process, and is directly related to the intensity of traffic. It should also present the most computable, stable, and accurate assessment of traffic diversion and uses of all multimodal facilities for freight. It involves a simple accounting procedure and is easily and accurately administered.

3. Much more attention should be given to appropriate and potentially harmonious intermodal cooperation at the water-surface break-bulk points. It is a known fact that ports, terminals, industrial parks, and private investors all desire to plan and engineer for both rail and water facilities. Historically, joint or through rates have been known to come into being only after the traffic demand has been well established and modal conflicts resolved at each individual break-bulk point. It is appropriate to begin to identify traffic impact points where rail and water interests could, in conjunction with dialogue with present and future shippers, develop through or joint rates that are closely integrated with the type of industrial development and, on the basis of forecasted traffic by commodity type, that improve both rail and water use as a result of present and future stability and attractiveness of price to the shipper.

This is the essence of the current legislative controversy. Although great differences exist in the House and Senate about the level of charge to be imposed, it is clear that one piece of legislation, the Domenici bill, prefers the capability of full recovery in the first round. In light of the past history of the waterways operator and an imprecise quantitative knowledge of the impacts of user charges, this appears to be initially inappropriate. We have only simulated output of the impact. Logically, it is appropriate to tie user charges to capital and operating cost recovery in a subsidy argument. Given that point, it is much more sound in an engineering and system management sense to apply some user charges, watch the system react, and respond to the experimental results with a building-blocks approach and thus develop a sound level of quantitative data than to impose full user charges at the outset, incur great multimodal instability in traffic and investment processes, and thereby create havoc in one or perhaps two modal components. Therefore, the conclusion is that we should impose user charges, coupled with facility recovery plans, but on a graduated and monitored basis.

Finally, it is appropriate to review the issues of user charges and transportation system investment in a multimodal frame of reference. This is particularly important when one views the last 7 years of emerging national transportation planning. We have lived, since 1971, through two studies of national multimodal transportation needs and capital improvement programs based on the most comprehensive requests for data ever made at the state level in our transportation history. In addition, Secretary of Transportation Coleman's administration put forth the National Policy Statement, and we currently have a 2-year commission scrambling to look at long-run needs and financing questions. The point is that to open the question of user charges in relation to rail versus water in this particular time frame is to ignore the core question of modal equity, related multimodal financing concepts, and the structure and place of the mode in current DOT organization. Future effort should be directed to intermodal or multimodal financing arrangements that assess and redistribute, through financing mechanisms, user charges and investment portions across all systems. Whether this takes the form of "one-pot funding" or separate trusts with borrowing provisions, such a detailed review should be made in conjunction with the detailed scrutiny now being given to the issue of rail-waterway facilities investment.

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