Upper Mississippi River and Illinois Waterways:

How to Reduce Waiting Times of Vessels While Using the Current Infrastructure

By

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1. Background

At the request of the Institute for Agriculture and Trade Policy (IATP) we have investigated into low-cost traffic management measures that have the potential to reduce waiting times of vessels on the Upper Mississippi River and Illinois Waterways (UMR-IW). Vessels using the UMR-IW encounter significant waiting time at certain locks during certain times of the navigation season. The U.S. Army Corps of Engineers (The Corps) is charged with the federal responsibilities of development and maintenance of the inland waterways in the U.S., and is currently evaluating expanding the capacities of congested locks on the UMR-IW (see Figure 1). Such an expansion will reduce (or even eliminate) the waiting times. The proposed project will require a large capital investment by the federal government, will take years to complete, and will have significant environmental impacts. IATP is interested in traffic management measures that can be quickly implemented, do not require a significant investment, and are friendly to the environment.

Figure 1: Locations of UMR-IW locks and dams

We have surveyed the literature dealing with the development and operation of the inland waterways in the U.S. with a focus on the UMR-IW, as well as the literature dealing with traffic management methodologies for various modes of transportation. An annotated bibliography of the more relevant literature is enclosed in the Appendix. We believe that our literature survey is comprehensive but by no means exhaustive. We did find some material regarding traffic management measures in the various modes of transportation, but most of what we found are theoretical models that have not necessarily been implemented. We shall refer to the relevant references throughout our report.

Before we begin the discussion we shall clarify a few terms. *Utilization* measures the fraction (or percentage) of time that a system is being used. High or low utilization is not necessarily directly related to waiting times of customers. One can have a system with high utilization with relatively short waiting times (think about an appointment system where customers make appointments to receive service). Moreover, if one reduces the average service times by 10% (a highly desirable change) without any other changes, both the system utilization and waiting times of customers will decrease. Therefore utilization is not a relevant measure of effectiveness. Finally the terms *queues* and *waiting lines* will be used interchangeably in this report.

The Corps collects and maintains operational data regarding the locks, and that data shows significant waiting times (hours, or even days) at certain locks during certain times in the UMR-IW system. Table 1 contains a list of all locks and dams on the Upper Mississippi River and Illinois Waterway, as well as selected information about tonnage and average wait times. Such delays affect the cost of the freight shipped through the UMR-IW system (see, for example, [9]). This report will focus on methods to reduce these queues (waiting lines) and waiting times. Although The Corps has investigated numerous low-cost (small-scale) measures (see [27]) we take a fresh look at the operational side from a somewhat broader perspective.

2. Characteristics of Queuing Systems

Before we discuss the issue of reduction in waiting times we must understand why queues form in the first place. Even in systems that are not fully utilized we can observe long queues that result in long waiting times.

The basic problem is that *unused service capacity cannot be stored for later use*. Therefore, when during a certain period of time (be it minutes or hours) a server does not have customers to serve, that service capacity is lost forever. That server will not be able to later serve more customers than its capacity. If a lock can serve, on average, two tows per hour, and it sits idle for an hour, that lock will not be able to catch up by serving four tows in the following hour.

Table 1: Locks on the UMR-IW, and selected information

UPPER MISSISSIPPI RIVER AND ILLINOIS WATERWAY LOCKS AND DAMS									
		Main Chamber		Auxiliary Chamber		1999 Tonnage (ktons)			1995-99
		Year		Year		Up-	Down-		Average
Lock	**Mile**	**Open**	**Size**	**Open**	**Size**	**bound**	**bound**	**Total**	**Wait Time (hours)**
				Upper Mississippi River					
Upper St. Anthony Falls	854	1963	400 x 56	-	-	1,543	521	2,064	0.0
Lower St. Anthony Falls	853	1959	400 x 56	1932	400 x 56	1,542	525	2,067	0.0
Locks & Dam 1	844	1930	400 x 56	1948	600 x 110	1,536	536	2,072	0.1
Locks & Dam 2	815	1930	500 x 110	-	-	3,065	8,474	11,539	0.5
Lock & Dam 3	797	1938	600 x 110	-	-	3,055	8,494	11,549	0.5
Lock & Dam 4	753	1935	600 x 110	-	-	3,168	9,172	12,340	0.4
Lock & Dam 5	738	1935	600 x 110	-	-	3,580	9,191	12,771	0.5
Lock & Dam 5A	729	1936	600 x 110	-	-	3,683	9,078	12,761	0.5
Lock & Dam 6	714	1936	600 x 110	-	-	3,812	11,981	15,793	0.7
Lock & Dam 7	702	1937	600 x 110	-	-	3,898	11,959	15,857	0.7
Lock & Dam 8	679	1937	600 x 110	-	-	4,496	12,330	16,826	0.9
Lock & Dam 9	647	1938	600 x 110	-	-	6,472	12,349	18,821	0.7
Lock & Dam 10	615	1936	600 x 110	-	-	6,787	15,219	22,006	0.8
Lock & Dam 11	583	1937	600 x 110	-	-	7,286	15,209	22,495	1.0
Lock & Dam 12	556	1938	600 x 110	-	-	7,351	17,076	24,427	1.0
Lock & Dam 13	523	1938	600 x 110	-	-	7,426	17,377	24,803	1.0
Locks & Dam 14	493	1939	600 x 110	1922	320 x 80	8,400	22,440	30,840	2.6
Locks & Dam 15	483	1934	600 x 110	1934	360 x 110	8,821	22,389	31,210	1.9
Lock & Dam 16	457	1934	600 x 110	-	-	9,647	23,492	33,139	1.6
Lock & Dam 17	437	1939	600 x 110	-	-	9,893	24,277	33,139	2.0
Lock & Dam 18	411	1937	600 x 110	-	-	9,854	25,853	34,170	2.1
Lock & Dam 19	364	1957	1200 x 110	-	-	8,350	27,454	35,707	0.8
Lock & Dam 20	343	1936	600 x 110	-	-	8,455	28,058	35,804	2.3
Lock & Dam 21	325	1938	600 x 110	-	-	8,880	28,984	36,513	2.3
Lock & Dam 22	301	1938	600 x 110	-	-	8,802	29,272	38,074	5.1
Lock & Dam 24	273	1940	600 x 110	-	-	9.242	30,055	39,297	4.1
Lock & Dam 25	241	1939	600 x 110	-	-	9,291	30,245	39,536	4.3
Melvin Price	201	1990	1200 x 110	1994	600 x 110	24,193	53,388	77,581	1.1
Locks & Dam 27	186	1953	1200 x 110	1953	600 x 110	25,629	57,750	83,379	3.1
				Illinois Waterway					
Thomas J. O'Brien	327	1960	1000 x 110	-	-	5,543	1,829	7,372	0.1
Lockport	291	1933	600 x 110	-	-	11,999	4,040	16,039	1.6
Brandon Road	286	1933	600 x 110	-	-	12,047	4,027	16,074	1.4
Dresden Island	272	1933	600 x 110	-	-	12,679	5,068	17,747	1.2
Marseilles	245	1933	600 x 110	-	-	12,258	6,898	19,156	1.6
Starved Rock	231	1933	600 x 110	-	-	12,595	8,789	21,384	1.3
Peoria	158	1938	600 x 110	-	-	14,125	17,004	31,129	1.9
Lagrange	80	1939	600 x 110	-	-	14,265	21,133	35,598	3.7

Waiting lines form when, during a short period of time, demand exceeds capacity. This happens even in an underutilized system. Let us consider as an example a lock that can serve an average of two tows per hour. If the lock is presently empty and during the next half hour three tows arrive, a queue will form because the lock cannot serve three tows in half an hour.

Variability in the arrival of customers and variability in service times are the source of the problem. If one could eliminate these two sources of variability one could eliminate the waiting lines and the resulting waiting times. If it takes a lock exactly thirty minutes to process a tow (two tows per hour), and tows arrive exactly thirty-five minutes apart there is no reason whatsoever for a waiting line to form. Even if tows arrive exactly thirty minutes apart (two per hour) there will be no waiting and the lock will be 100% utilized. However, such a scenario is not realistic under current operating procedures.

Queues are not linear with regard to changes in arrival rates or service times. Generally, when there is variability in arrivals of customers and/or in service times, the average length of the queue and the average waiting time both grow exponentially when the utilization of the servers approaches full utilization (see Figure 2). Therefore such queuing systems should not be planned for full utilization of the servers because queues and waiting times become very long. Moreover, a relatively small reduction in demand (say 10%) in a system that is highly utilized can drastically reduce the queues and waiting times. We can also look at the length of the queue (and the waiting time) from a different perspective. Doubling the service capacity of a system that has long queues will not cut the queues by half, but rather almost eliminate them. For example, if an airport concourse has a single security checkpoint for passengers and the average waiting time of passengers for the security check is 20 minutes, and the utilization of the checkpoint is 90%, adding a second checkpoint operating in parallel will almost eliminate the waiting times (and not cut them in half), but the utilization of the checkpoints will drop to 45%. The basic tradeoff in designing queuing systems is between the cost of providing the service and the cost of customers' waiting. When one cost goes up, the other goes down. Therefore queuing systems should be designed to minimize the sum of these two costs.

In view of the characteristics discussed in this section there are several strategies available to reduce waiting lines and waiting times in existing queuing systems before increasing their capacity:

1. Reduce the level of demand for the service
2. Reduce the variability of demand
3. Reduce the variability of service times
4. Reduce the average service time

The first two strategies fall under the heading of "Demand Management" and are discussed in the following section. The third and fourth strategies have more to do with internal operational procedures and will be discussed in a later section.

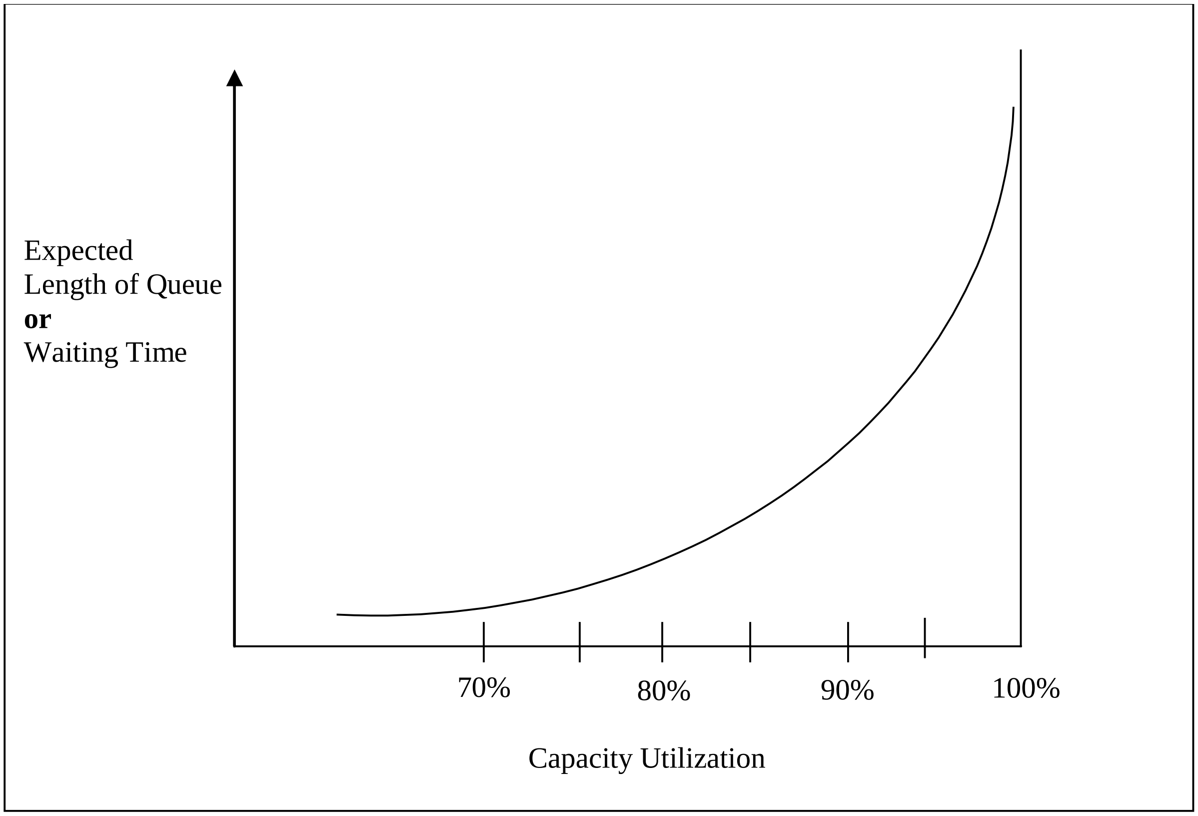

Figure 2: Typical relationship between waiting time and capacity utilization in a queuing system.

3. Demand Management

Many industries use a variety of strategies to manage demand. When demand levels are not constant over time, then periods of peak demand are evidenced. If the system capacity is insufficient to serve the periods of peak demand, then waiting lines result or (in a competitive environment) demand may be lost to competitors. Thus the objective of demand management is to lower the level of peak demand in order to avoid the necessity to increase capacity to meet the peak demand. Investments in service capacity are usually very expensive and increasing capacity to meet peak demand will usually result in poor average capacity utilization over time. For example, in the electricity generating industry, utility companies often try to meet peak demand for electricity by purchasing surplus power from other electric utilities. Thus, initially, one should attempt to smooth demand patterns before adding service capacity.

Demand management tools can be separated into two types:

1. Financial measures
2. Operational measures

Financial Measures use pricing mechanisms to change demand patterns. Customers are offered price incentives (discounts) to use the system during low demand periods or are penalized (pay a premium price) for using the system during peak periods. The Washington D.C. Metro system charges almost double the base fare for riding the system during rush hours. Electrical utilities charge discounted rates to large customers who allow the utility to disconnect them from the grid during peak demand periods. Manufacturers of high volume seasonal products give deep discounts to distributors who are willing to take early delivery of their products. All these measures allow the operator to smooth peak demand and avoid investments in additional capacity. In addition, differential pricing among customers based on customer volume allows operators to fend off undesirable demand and to reduce overall demand level.

Operational Measures are often used to smooth demand patterns when financial measures are not applicable. Many transportation services publish service schedules and customers have to fit their desired travel into the published schedule (airlines, bus lines, liner ships, railroads). The service schedule itself is affected by the capacity of the facilities used and by the available equipment. Often such scheduled service is combined with differential pricing (in order to encourage usage in low demand periods). A similar approach is an appointment system where customers are assigned appointed times to be served. Appointment systems are common in healthcare (physicians' offices, scheduled admissions to hospitals) and in many other professional services, as well as in transportation (assignment of take-off and landing slots to airlines in congested airports, air traffic control management).

In a similar vein, the FAA's Air Traffic Control system maintains maximum use of airport landing capacity by holding incoming scheduled planes on the ground at their origin for departure clearance whenever there is anticipated congestion at the destination airport. Thus not only is there an appointed departure time to adhere to, there is also active management of the arrival times in order to save on fuel and to minimize congestion at capacity-constrained airports. Permitting individual airplanes to "pile up" in the airspace of an airport would be extremely inefficient and costly to airlines and (eventually) to passengers. Given the immense cost of building additional peak time airport capacity and the long-term nature of such additions, every attempt is made to maximize the utilization of existing capacity prior to adding capacity. The overall cost to both the airline industry and the airport is thereby minimized.

4. Capacity Management

Changing the capacity of an operation (number and/or size of facilities) is usually a long-term proposition and requires significant capital investment. However, in the short run adjustments in existing capacity in order to meet peak demand are made using several approaches:

1. Extending operating hours
2. Using subcontractors
3. Activating temporary capacity that is expensive to operate but relatively cheap to install (electrical utilities activate gas generators during peak demand periods)
4. Building inventories during low-demand periods to address peak demand

Since the locks in the UMR-IW system operate around the clock, there is no alternative to using their service when navigating the river and since their service cannot be inventoried, so these four approaches are impractical for further consideration.

5. Congestion in Transportation

Traffic jams on the roads are a daily phenomenon. However, alternate routes are often available. Thus, making drivers aware of congested roads may divert traffic to other routes, or divert drivers (at least temporarily) to other activities such as shopping. In certain cases fast alternate routes may be available at a fee (toll roads). So, the emphasis (at least in the short run) is to make drivers aware of congested roads and let them make their own decisions (see [17] and [22]). In the long run, roads are widened and new roads are built, but that increased capacity itself increases demand and merely relocates the traffic jams to different locations. Congestion exists also in road transportation service facilities. Truck drivers often must make appointments at loading docks to load or to deliver their cargo.

The fast expansion of air travel during the last several decades combined with the lack of increase in airport capacity has resulted in excess demand for services at certain airports. The common practice in such cases is to allocate take-off (and landing) slots to the various operators, thus assuring that demand will not exceed the operational capacity of the airport (see [1] and [11]). However, usually these are slots for recurring operations (daily or weekly frequency). The initial allocation of slots is usually based on the level of activity of each operator. Sometimes such slots are later sold to other operators (usually with other assets and with government approval), or returned to the airport for reallocation. However, such slots are seldom auctioned off.

As far as waterways are concerned, congestion in certain ports is also a common phenomenon, especially for non-containerized general cargo. An analysis of queuing at the Suez Canal is provided in [12], but there ships pass the whole length of the canal in convoys. A traffic information system for the Danube River is described in [21]. Such a system may provide the data necessary for scheduling the traffic on the river. Finally, comparison of the operation of different priority rules for handling queues at a lock is provided in [26].

6. Possibilities for Reduction of Waiting Times

The lack of direct user fees (where users pay for the services that they actually use) limits to a large extent the range of tools available to manage demand for the services of the locks in the UMR-IW system. Presently the only “user fee” paid directly by the users of the system is the fuel tax. If that fuel tax is increased significantly, it will result in the shifting of cargo to alternate transportation modes (mainly rail) or to alternative markets and in a reduction of the overall demand level for the services of the locks. Such a shift in demand will result in significant reductions in waiting times. We understand that the imposition of direct user fees or significantly increasing the existing fuel tax are politically charged long-term propositions and, therefore, we shall focus on other measures that can be implemented in shorter time frames.

At this point we are left with operational measures. The objectives of such operational measures are:

1. To reduce the variability in demand (arrival times of tows)
2. To reduce the average service time at the locks
3. To reduce the variability of service times at the locks.

6.1 Reducing Demand Variability

We believe that one of the most effective ways for reducing the total waiting time of users is to reduce demand variability by implementing an appointment system. Such a system will not only reduce the average waiting time of all users, but may also save significant amounts of bunker fuel due to slower steaming of tows. The Corps considered a "Scheduling Program" among the small-scale measures (see [27]), but it had a much narrower scope and referred only to implementing an "N-up/M-down" operating rule at locks when large queues were present. The Corps claimed that such an operating rule was already being applied when warranted.

An envisioned appointment system could operate as follows. When a tow exits one lock and/or starts moving towards the next lock it notifies the lockmaster of its current position and its estimated time of arrival (ETA), and receives a time slot for a service appointment at the destination lock. The current position of the tow can be verified via a GPS system, and additional policies to prevent abuse of such a system may have to be implemented. If the tow misses the service appointment, it will have to wait until a time slot becomes available. Operational efficiencies can be taken into account in the planning of the time slots. If there are reductions in average service times, or in the variability of service times, by scheduling multiple movements in the same direction (either up or down the river) then sequences of such movements should be scheduled.

Generally, bunker fuel consumption of a (diesel powered) motor ship is proportional to the third power of its speed. Thus, reducing the cruising speed by 20% results in 50% reduction in bunker fuel consumption (see [23]). We suspect that a similar relationship holds for tows. Presently tows are served by the locks on a "first come, first served" basis. This operating policy results in tows steaming at full speed towards the locks and then waiting for service ("hurry up and wait"). Getting a service appointment for the next lock will allow the tows to steam at reduced speed and thus save a significant amount of bunker fuel and still pass through the lock at about the same time. The time that is presently spent waiting at the lock will be spent steaming at a reduced speed. Thirty years ago, during the oil crisis, a similar concept was proposed for the Panama Canal. Ships had to wait several days to join a convoy to pass through the canal. By getting appointments they conceivably could steam at a slower speed, save bunker fuel, and still get to the canal entrance on time to join their convoy. The major obstacle to that system was the fear of cheating (ship operators will not necessarily report their true geographical location and thus will get an earlier passage time). However, now this concern can be addressed with a GPS system that allows the lock operator to verify the location of each tow.

A further investigation into the feasibility, cost, time frame, and required changes in operational procedures is necessary in order to study the potential benefits from such an appointment system. We believe that a simulation model will have to be an integral part of such an additional investigation. A simulation model will allow evaluation of the impact of different operating rules and different scheduling policies on waiting times at the locks, lock throughput, and the associated potential bunker fuel savings. An appointment system will most likely require investment in some computer hardware and the development of computer software to manage the appointments.

6.2 Reducing Service Times and Their Variability

The use of an “N-up/M-down” operating rule appears to reduce overall variability in service time. Therefore a “first come, first served” service policy while appearing equitable, is in effect inefficient and increases the total waiting time of all users.

The Corps prepared a report in April 1999 entitled, “Summary of Small-Scale Measures Screening” [27]. This is a comprehensive report that considers over ninety congestion management options. Such options run the gamut from scheduling to lockage and/or channel improvements to tow/barge design. In general these options were presented with an eye toward reducing the service time for a tow to proceed through a given lock. Such a reduction in service time would also tend to reduce the length of the queue.

It is important to be cognizant of the fact that the improvements posited in the report are not, in general, additive in nature. That is, if two different tow improvements are hypothesized to save an average of five minutes each per tow, it does not necessarily follow that implementing both improvements simultaneously would result in a total of ten minutes saving per tow. Rather, simultaneous implementations in all likelihood would result in a saving somewhere between five and ten minutes per tow.

Because nearly four years have elapsed since the publication of “Summary of Small-Scale Measures Screening”, we recommend that the over ninety congestion management options be revisited. We base this recommendation on the fact that numerous technological improvements have occurred during that time. For example, consider the explosion of computer technology including more powerful and cheaper laptop computers, the continued expansion of global positioning systems (GPS) and geographical information systems (GIS), as well as other advances in technology directly affecting maritime transportation. A case in point is the use of laptop computers and GPS technology on the St. Lawrence Seaway System (SLSS). Beginning early this year, all commercial vessels on the SLSS will be required to have the automatic vessel identification system (AIS). Each vessel will be equipped with a transponder and a laptop computer. Three Seaway Vessel Traffic Control Centres (TCCs) will be able to transmit information such as the location of other vessels in the area, water levels, current wind speed and direction, and lock order turns.

7. Summary

With the goal of reducing waiting times at locks of the UMR-IW system we have undertaken an extensive literature search in the areas of inland waterways and traffic management for various modes of transportation. Viewing the problem as a queuing system has enabled us to categorize the problem utilizing concepts such as demand management, capacity management, and congestion management.

After reviewing various low-cost (small-scale) measures we recommend that:

1. The feasibility of, and the benefits from establishing an appointment system for scheduling tows at the locks be further investigated
2. The small-scale measures evaluated by The Corps in 1999 be revisited

Lack of access to the operation of the locks limits our ability to make a more detailed evaluation of operational measures to reduce waiting times.

Appendix

Annotated Bibliography

1. Abeyrante RIR, **Management of Airport Congestion Through Slot Allocation,** *Journal of Air Transport Management*, 2000, 6(1)29-41.
The lack of airport slots (the time allocated for aircraft to land or take off), particularly at airports which experience congestion, have reached unmanageable proportions in recent years. The International Civil Organization (ICAO) records that, by the end of 1997, there were 132 slot controlled international airports, (118 year round and 14 during peak seasons). Between 1989 and 1998 the reported number of commercial aircraft in service increased by about 60% from 11,253 to 18, 139 aircraft. In 1998, 1463 jet aircraft were order, compared with 1309 in 1997, and 929 were delivered compared with 674 in 1997. In 1998, the total scheduled traffic carried by airlines of the 185 Contracting States of ICAO amounted to a total of about 1462 million passengers and about 26 million tons of freight. These figures are reflective of the rapidly increasing frequency of aircraft movements at airports, calling for drastic management of airport capacity. To cope with the demand, airlines are forming strategic alliances with themselves by utilizing such commercial tools as franchising, leasing and interchange of aircraft. The management of airport capacity through slot allocation is a critical consideration for the world aviation community. This article analyses the problem and discusses various issues related thereto.

2. Babcock MW and Xiaohua L, **Forecasting Inland Waterway Grain Traffic,** *Transportation Research part E*, 2002, 38, 65-74
The purpose of this paper is to address a neglected area of water transportation forecasting — short-term forecasting of inland waterway traffic. A time series model is used to forecast Mississippi River Lock 27 grain tonnage for the 1989:1-1999:4 period. The model was selected on the basis of several measures of goodness of fit and out-of-sample forecasting performance. The out-of-sample forecasting performance of the model was good, as the percentage difference between the year 2000 actual and forecasted tonnage was less than 5.5% for three of the four quarters and only about 2% for the year.

3. Dai MDM and Schonfeld PM, **Metamodels for Estimating Waterways Delays through a Series of Waterway Queues,** *Transportation Research Part B*, 1998, 32(1)1-19.
A numerical method has been developed for estimating delays on congested waterways. Analytic and numerical results are presented for series of G/G/1 queues, i.e., with generally distributed arrivals and service times and single chambers at each lock. One or two-way traffic operations are modeled. A

metamodelling approach which develops simple formulas to approximate the results of simulation models is presented. The structure of the metamodels is developed from queueing theory while their coefficients are statistically estimated from simulation results.

The numerical method consists of three modules: (1) delays, (2) arrivals, and (3) departures. The first estimates the average waiting time for each lock when the arrival and service time distributions are known. The second identifies the relations between the arrival distributions at one lock and the departure distributions from the upstream and downstream locks. The third estimates the mean and variance of the departure times when the interarrival and service time distributions are known.

The method can be applied to systems with two-way traffic through common bi-directional servers as well as one-way traffic systems. Algorithms for both cases are presented. This numerical method is shown to produce results that are close to the simulation results.

The metamodels developed for estimating delays and variances of interdeparture times may be applied to waterways and other series of G/G/1 queues. These metamodels for G/G/1 queues may provide key components of algorithms for analyzing networks of queues.

4. Dai MDM, Schonfeld PM and Antle G, **Effects of Lock Congestion and Reliability on Optimal Waterway Travel Times,** *Transportation Research Record*, Paper No. 930596, 1993

The congestion and variability of service times at locks significantly affect the cost and reliability of waterway transportation. This paper considers the effects of lock congestion levels and reliability on the operating cost of tows, assuming that tow operators have the opportunity to optimize speed in response to the delays they have already experienced and the delays they expect to encounter. The analysis method in this paper is useful for evaluating long-term consequences of lock improvements, as well as for optimizing speed from the viewpoint of operators.

This analysis method optimizes tow operations in two stages. The first stage finds the optimal speeds for each individual tow, re-optimizing the speed after every lock. The second stage determines the optimal allowed delivery times and associated optimal speeds based on the lock transit time distributions. The optimization is guided by a total cost objective function which includes penalties for late deliveries.

A four-lock section on the Ohio River is used for a case study in which various congestion levels and speed limits are tested. The resulting total cost functions are U-shaped with respect to the allowed delivery times. At given congestion levels, the optimal allowed delivery times and costs decrease as speed limits increase. The results also show how the optimal allowed delivery times and costs increase as congestion becomes severe.

5. Doxsey L, **Incentive Tolls for Congestion Management,** *Transportation Research Record 1576*, 1997, 77-84.
A congestion pricing planning model was developed for the Port Authority of New York and New Jersey. The model is designed to evaluate possible incentive tolls for their effects on congestion delays at the six bridges and tunnels the authority operates between New Jersey and New York. The study used a stated preference survey administered to bridge and tunnel users, econometric choice models, and plaza volume-delay relationships as a basis for simulating the effects of changes in toll structure. The survey identified characteristics of trips, and the trip makers. A stated preference choice exercise was included to reveal trade-offs among toll, plaza delay, facility choice, and time period when the crossing would be made. Responses to the exercise were combined with other survey data, and econometric models of choice were estimated. The models associate the probability of travel choices with the conditions faced at the alternatives. The policy evaluation planning model combined choice model results, survey responses from individual respondents, and data on facility conditions, volumes, and capacities. As input it accepts a user-specified menu of tolls and discounts, potentially varying both by hour and by facility. As output it predicts automobile volumes, average delays, total delays, and toll revenue by hour and facility. The model is constructed to achieve equilibrium among tolls, delays, and volumes. Application of the model indicates considerable potential for reducing plaza delays.

6. Fellin L and Fuller S, **Effect of Proposed Waterway User Tax on U.S. Grain Flow Patterns and Producers,** *Transportation Research Forum***,** 2000(?), pp. 11-25.
The administration recently proposed the barge fuel tax be increased from $0.20/gallon to $1.20/gallon. Because the increased tax could have important implications on U.S. agriculture, quadratic programming models of the soybean/corn sectors are used to evaluate the impact on flow patterns, producer prices/revenues and export levels. Results show the tax increase would divert 10.6 million metric tons from the inland waterways; 70 percent of the diversions are from the upper Mississippi/Illinois systems. The lower Mississippi River port area is projected to lose 9 million tons, while other Gulf, Great Lakes, north Atlantic and Pacific northwest ports increase by 3.35, 1.49, 1.74 and 1.40 million tons, respectively. Soybean/corn producers in Minnesota, Illinois and Iowa incur annual revenue losses of $151 million and about 75 percent of the expected decline in all producer revenues. Exports of U.S. soybeans are nearly unchanged with the proposed tax increase while corn exports decline 2.16 percent. If the proposed tax were implemented, barge-transported soybeans/corn would increase federal revenues by $89 million per year. The proposed tax increase has unfavorable implications for U.S. producers, grain handling/exporting industries and barge transportation firms, however, the impact is not judged to be calamitous.

7. Ferguson E, **Three Faces of Eve: How Engineers, Economists, and Planners Variously View Congestion Control, Demand Management, and Mobility Enhancement Strategies,** *Journal of Transportation and Statistics*, April 2001, 51-73.

The political acceptability (A) of public policy measures correlates positively with program effectiveness (E) and negatively with program cost (C) and other obstacles to implementation (I) under normal circumstances. Ferguson (1991) observed that the political acceptability of many demand management strategies seemed to correlate negatively with implied program effectiveness. Engineers, economists, and planners each have their own unique professional standards. Increased effectiveness is the primary goal of engineering. Improved efficiency is the generally accepted standard in economics. Process issues are of vital concern in planning. A review of the literature indicates few studies in terms of all four variables of interest (A, E, C, and I) simultaneously. Three relevant studies are identified: one each by an engineer, an economist, and a planner. Raw data, regression results, bivariate correlation, and model output reveal that two of the three studies support the Ferguson hypothesis. The other supports a more traditional public policy model. E is the most influential variable in the engineer's data. C is the most influential variable in the economists' data, while I is the most influential variable in the planner's data. These revealing results suggest the subtle manner in which professional training and experience may alter perceptions of transportation and policies and programs in professional practice.

8. Forsyth P, **Privatisation and regulation of Australian and New Zealand Airports,** *Journal of Air Transport Management*, 2002, 8, 19-28.

A brief background on the Australian and New Zealand airports is provided at the beginning of the paper. This is followed by a discussion of the approach to price regulation which Australian regulators are implementing in other industries; this gives an indication of how the—as yet new—regulation of airports will develop. Some specific regulatory issues are next considered; firstly, the merits of the dual till approach are considered, and then how the regulator is handling investments in new capacity. The New Zealand policy of no formal price regulation is examined; this is a less "light handed" form of regulation than it seems. Finally, the main problems of privatising and regulating Sydney are discussed.

9. Fuller S and Grant W, **Effect of Lock Delay on Grain Marketing Costs: An Examination of the Upper Mississippi and Illinois Waterways,** *Logistics and Transportation Review***,** 1993**,** 29(1)81-95

This paper evaluates the effect of lock delay on the efficiency of marketing the North Central U.S.'s corn and soybean production via the upper Mississippi and Illinois waterways. The analysis is accomplished with a multi-commodity least-cost network flow model. Lock delay was found to have an important effect on the cost of barging the region's surplus grain production. If the lock and dam system on the upper Mississippi and Illinois waterways is not continually upgraded, grain is redirected to less efficient modes, thus increasing the cost of

marketing the region's grain surplus. These increased costs need to be weighed against the costs of upgrading lock capacity.

10. Gervais JP, Misawa T, McVey MJ and Baumel, P, **Evaluating the Logistic and Economic Impacts of Extending 600-Foot Locks on the Upper Mississippi River: A Linear Programming Approach,** *Journal of the Transportation Research Forum*, Fall 2001, 40(4)83-103.
This article uses a highly disaggregated linear programming model to evaluate the short-run benefits of extending five 600-foot locks on the Upper Mississippi River (UMR) to 1,200 feet. We model 1994-1995 corn flows in three counties of eastern, central, and western Iowa. Two scenarios are simulated based on either completed or partial pass-through of the cost savings associated with large-scale improvements on the UMR to grain elevators and producers. The estimate of the total annual costs of lock expansions is 4 cents a bushel. Total annual benefits accruing to grain producers and elevators are in the range of 0.21 to 0.43 cents a bushel. No environmental costs are included in the analysis.

11. Golaszewski R, **Reforming Air Traffic Control: An Assessment from the American Perspective**, *Journal of Air Transport Management*, 2002, 8(1)3-11.
This paper examines institutional and economic reform of the ways in which air traffic control (ATC) services are provided in the U.S. It also contrasts the European and U.S. ATC systems in terms of size, scope, cost and organizational form. The paper suggests that many of the congestion and delay problems experienced in the U.S. result from the inefficient provision and use of air traffic capacity in the airport area, and these conditions are likely to continue or worsen if economic principles are not used to organize and provide ATC services. The paper notes that, while Europe has advanced more rapidly in the organizational and economic reform of providing ATC services, other problems remain. Because most large European airports have slot controls to limit demand in the airport area, its ATC congestion is more pronounced in the enroute environment.

12. Griffiths JD**, Queueing at the Suez Canal,** *Journal of the Operational Research Society***,** 1995, 46(11)1299-1309.
This paper describes an investigation into the delays experienced by ships waiting to pass through the Suez Canal. The main objective of the Suez Canal Authority (SCA) is to provide an attractive service to ship-operators, and in doing so maximize the income received from canal tolls. Thus, SCA wishes to maximize the throughput of vessels, but also requires queueing delays to be held at an acceptable level. This paper quantifies both measures (throughput and delays), and illustrates how they are in conflict to some extent. The study is somewhat unusual in that it affords the opportunity to employ more than one OR technique (linear programming and queueing theory/simulation) in the quantification process. Some of the work reported was undertaken in a consultative capacity, and the remainder as part of an ongoing research programme.

13. Hauser RJ, Beaulieu J and Baumel P**, Impact of Inland Waterway User Fees on Grain Transportation and Implied Barge Rate Elasticities,** *Logistics and Transportation Review*, 1985, 21(1)
This study analyzes the effects of proposed waterway user charges on grain shipments. Two types of full-recovery user fees are included, a fuel tax and a segment-specific ton-mile tax. An interregional linear programming model is used in which cost coefficients of the base model are changed to reflect user-fee effects on barge rates. The model includes over 200 grain originating points to 67 domestic destinations and 15 export areas and from the port areas to 6 overseas regions. Rail, barge and truck loadings are estimated (including combination movements) with and without waterway user-fees. Implied demand elasticities for barge travel are estimated. Significant shifts in shipment patterns take place depending on the location.

14. Kerr GN, **Managing Congestion: Economics of Price and Lottery Rationing**, *Journal of Environmental Management,* 1995, 45(4)347-364.
It is not uncommon for the carrying capacity for congestible facilities to be estimated before the allocation method is known. This paper shows how efficient capacity differs between two competing resource allocation mechanisms, one which is efficient (price) and one which is fair (lottery). The welfare theoretic implications of adopting lottery allocation rather than price allocation are illustrated from the perspectives of economic efficiency and the benefits obtained by resource users and suppliers. It is found that risk-neutral resource users will always prefer lottery allocation to price allocation. While price allocation is efficient, it is never in risk-neutral resource users» interests to have price allocation imposed. Conclusions are tested using a linear constant crowding demand function, in which case it is found that the efficient capacity for lottery rationing exceeds the efficient capacity where price is to be used to allocate a congestible resource. Objectives may be better met by joint use of allocation mechanisms, the implications of which are investigated using the linear demand model.

15. Khisty CJ, **Waterway traffic analysis of the Chicago River and lock,** *Maritime Policy and Management*, 1996, 23(3)261-270.
The vessel-carrying capacity of the Chicago River, Illinois, is restricted by a lock, separating the river from Lake Michigan. Currently, vessels passing through the lock experience long delays during summer months. An investigation and analysis of this system determined that although the system is now generally operating below capacity, the peak periods during summer weekends do approach capacity, and the situation is likely to deteriorate in the future. In addition, the river and lock have safety and traffic conflict problems that need attention. Recommendations to mitigate these problems are described.

16. Lari AZ and Buckeye KR, **Evaluation of Congestion Pricing Alternatives in the Twin Cities,** *Transportation Research Record 1576*, 1997, 85-92.
A congestion pricing study for the Twin Cities metropolitan area was conducted in 1995-1996 by the Minnesota Department of Transportation and the Metropolitan Council of Minneapolis and St. Paul (Twin Cities), with sponsorship by FHWA. The effort was designated a congestion pricing preproject study by FHWA. After an initial screening, 11 pricing options for the Twin Cities were considered. Five regionwide pricing options were ultimately evaluated in detail. Because of the need to understand the relationships and effects of various pricing options, it was necessary to develop and apply adequate evaluation criteria to those options. An evaluation matrix was created to help planners and decision makers make recommendations concerning the implementation of congestion pricing options and pricing features within those options that best meet identified objectives.

17. Logi F and Ritchie S, **Development and evaluation of a knowledge-based system for traffic congestion management and control**, *Transportation Research Part C*, 2001, 9(6)433-459.
This paper describes a real-time knowledge-based system (KBS) for decision support to Traffic Operation Center personnel in the selection of integrated traffic control plans after the occurrence of non-recurring congestion, on freeway and arterial networks. The uniqueness of the system, called TCM, lies in its ability to cooperate with the operator, by handling different sources of input data and inferred knowledge, and providing an explanation of its reasoning process. A data fusion algorithm for the analysis of congestion allows to represent and interpret different types of data, with various levels of reliability and uncertainty, to provide a clear assessment of traffic conditions. An efficient algorithm for the selection of control plans determines alternative traffic control responses. These are proposed to an operator, along with an explanation of the reasoning process that led to their development and an estimation of their expected effect on traffic. The validation of the system, which is one of only few examples of validation of a KBS in transportation, demonstrates the validity of the approach. The evaluation results, in a simulated environment demonstrate the ability of TCM to reduce congestion, through the formulation of traffic diversion and control schemes.

18. Martinelli D and Schonfeld P, **Approximating Delays at Interdependent Locks**, *Journal of Waterway, Port, Coastal and Ocean Eng.*, Nov. 1995, 121(6)300-307.
As with much of the nation's infrastructure, the inland waterway system is in critical need of expansion and repair. Many of the inland waterway lock and dam facilities have become major constraints to navigation due to increased traffic and facility deterioration, leading to costly delays. Because funds for lock and dam improvements are severely limited, comprehensive analysis methods are necessary to ensure efficient allocation of resources among the many proposed improvement projects. Unfortunately, lock and dams are often treated as independent facilities with regards to operations, when in fact, there are likely to be significant interdependencies between locks when considering lock

improvements. In this paper, a method is developed whereby the delays of a set of interdependent locks may be calculated. By incorporating interdependencies into benefit calculations of lock improvement projects, a more comprehensive assessment of improvement priorities can be established.

19. Niemeier HM, **Regulation of Airports: the Case of Hamburg Airport - A View from the Perspective of Regional Policy**, *Journal of Air Transport Management*, 2002, 8, 37-48.
There are currently divergent trends in the regulation of airports in Germany. While traditionally airports have been regulated by cost-based regulation, a price cap regulation for Hamburg airport has been implemented in 2000. Given the objectives of economic welfare and efficiency the paper argues that the old system is inefficient and results in a misallocation of resources. Regulation should be reformed by capping prices. An independent regulator should be established. Regulatory reform should be combined with reforms to intensify competition such as slot auctioning, further privatization with cross-ownership controls and open skies.

20. Perakis AN and Li J, **Recent technical and management improvements in US inland waterway transportation,** *Maritime Policy and Management*, 1999, 26(3)265-278.
Over the last several years, the US inland waterway transportation industry has significantly reduced its fuel consumption and improved its efficiency, with the side effect of less fuel tax collected per ton of cargo carried, despite the increase in cargo traffic. Fuel tax revenues are used for rehabilitation and construction projects on the inland waterway system, hence the US Army Corps of Engineers, providing us with relevant data over the interval in question, asked us to investigate this surprising reduction, and determine the main technical and fleet management improvements that caused it. Our research involved both visits with most major US inland waterways fleets, interviews with their engineers and managers, as well as statistical analysis of the above data. Technical improvements (such as engine plant efficiency increases), lighter, stronger building materials (such as light steel), and improved designs for better hydrodynamics, were not as important compared to management improvements (such as the use of computer-aided monitoring systems and advanced telecommunications, optimized tow configuration and speed, and increased triangular trips as opposed to simple round trips with returns empty). In addition, the demand for less expensive, imported steel for the US has resulted in an increased percentage of fully loaded return trips from New Orleans to the US Midwest, and hence also in increased fleet utilization.

21. Pfliegl R, **Innovative Application for Dynamic Navigational Support and Transport Management on Inland Waterways: Experience From a Research Project on the Danube River**, *Transportation Research Record 1763,* 2001, pp. 85-89.

The widespread use of inland waterways as a common transport mode is a main objective of European traffic policy, specifically in view of the expected dramatic increase in transport along the Trans-European Network, a main economic lifeline in Europe. Transport operators' limited acceptance of the inland waterway reflects unreliable calculations of estimated time of arrival, shifting water levels or other environmental events, unexpected delays in passing locks and borders, and insufficient transport monitoring capability. Implementing a telematics-based river information service will help to alleviate waterway transportation problems on the Danube River early in the day and improve the safety and productivity of transportation by integrating river-based transport information services with the intermodal transport chain. The proposed system meets the requirements of the Supreme Shipping Authority of Austria to generate a tactical and strategic traffic image on the Danube in Austria to fulfill its legal commitments to ensure safe and secure transport operations on the Danube. Communications interfaces will link the Austrian network connecting other users downstream as well (e.g., Hungary, Slovakia). Traffic information services will be provided to ship operators, ship owners, and transport operators carrying people and goods. The system consists of a transponder-based network using radio links embedded in a wire-based communications network on shore controlled by central management facilities providing tactical traffic information on a geographic-information-system-based application. A separate system and network management unit will ensure safe operations with a low failure rate, depending on the level of redundancy implemented. The overall system concept uses the results and provisional standards defined in the European Union project Inland Navigation Demonstrator for River Information Services.

22. Quiroga CA, **Performance measures and data requirements for congestion management systems,** *Transportation Research Part C*, 2000, 8, 287-306.
Many metropolitan areas have started programs to monitor the performance of their transportation network and to develop systems to measure and manage congestion. This paper presents a review of issues, procedures, and examples of application of geographic information system (GIS) technology to the development of congestion management systems (CMSs). The paper examines transportation network performance measures and discusses the benefit of using travel time as a robust, easy to understand performance measure. The paper addresses data needs and examines the use of global positioning system (GPS) technology for the collection of travel time and speed data. The paper also describes GIS platforms and sample user interfaces to process the data collected in the field, data attribute requirements and database schemas, and examples of application of GIS technology for the production of maps and tabular reports.

23. Ronen D, **The Effect of Oil Price on the Optimal Speed of Ships**, *Journal of the Operational Research Society*, 1982, 33, 1035-1040.
The tradeoff between fuel savings through slow steaming on the one hand, and the loss of revenue due to the resulting voyage extension on the other hand is analyzed, and three models for the explicit determination of the optimal speed of a

ship are presented. Each model is applicable under different schedule of revenues, and the optimal speed is a solution to a cubic equation over the feasible range of cruising speeds.

24. Southworth F, ***Analysis of Lock Transit Curves Options For Use in Modeling Upper Mississippi and Illinois River Locks***, 2002, Oak Ridge National Laboratory.
The purpose of the analysis described in this report was to assess the accuracy and robustness of two simplified lock transit time estimation methods for use in the economic analysis of Upper Mississippi and Illinois River lock improvements. As such, the study is part of a larger effort to estimate the dollar savings to shippers from the provision of a navigable waterway along the Upper Mississippi and Illinois Rivers. This larger study has been charged with analyzing river traffic by using the US Army Corps of Engineers (USACE) Tow Cost – Equilibrium (TCM/EQ) modeling system to simulate annual flows up and down these two rivers, including the passage of tows through locks. Accurate and robust lock transit time estimates are crucial to such a study, because traffic congestion at locks can cause significant and costly delays to tows.

25. Tellis R and Khisty CJ, **Social Cost Component of an Efficient Toll,** *Transportation Research Record 1576*, 1997, 140-146.
Efficient tolls are tolls that ensure that the price paid by the roadway user is equal to the increment of social and private costs resulting from the highway use. Setting these tolls accomplishes an important objective: to correct the current practice that allows driving to be subsidized by government and non-users. Without restrictions on vehicle ownership and unlimited access to the nation's cost-free roadways, drivers do not pay for the social costs they generate. If motorists were required to pay their fair share of these social costs, travel decisions would probably be altered. Unwarranted trips, especially during peak hours, would be reduced because roadway space would be priced to accurately reflect the actual cost of driving. Beyond private costs, society is burdened with paying for infrastructure construction and maintenance, highway services, wasted fuel, pollution, accidents, and congestion costs from travel delays. The cost to society of automobile travel is assessed so that a charge can be made for the social cost component in computing what an efficient toll should be. It is found that the social cost fee during non-peak travel comes to 0.67¢/vehicle-km (1.08¢/vehicle-mi). Travel during peak periods is far more expensive with the addition of congestion costs. The value of time drives up these costs, and the charges amount to 5.68¢/vehicle-km (9.14¢/vehicle-mi) for peak-period travel.

26. Ting CJ and Schonfeld P, **Efficiency Versus Fairness in Priority Control: Waterway Lock Case**, *Journal of Waterway, Port, Coastal & Ocean Eng.*, March/April 2001, 127(2) 82-88.
Delay at a congested service facility, such as a waterway lock, depends on the control policy used. The shortest processing time first (SPF) policy, which is a promising priority control policy, can significantly reduce the average delay/barge

compared to the normally used first come first served (FCFS) policy. SPF tends to favor large groups of barges, i.e., tows, at the expense of smaller ones. This paper modifies the SFP policy to consider fairness among tows in queues. One modified algorithm, called fairer SPF (FSPF), limits the number of tows allowed to pass any particular tow. The case study indicates that FSPF can yield most of the benefits of SPF without greatly sacrificing fairness.

27. U.S. Army Corps of Engineers***, Upper Mississippi River - Illinois Waterway System Navigation Study: Summary of Small-Scale Measures Screening (Interim Report),*** April 1999, Rock Island, St. Louis, and St. Paul Districts
The Upper Mississippi River—Illinois Waterway System Navigation Study (Navigation Study) is a feasibility study addressing navigation improvement planning for the Upper Mississippi River and Illinois Waterway (UMR-IWW) systems for the years 2000-2050. This study assesses the need for navigation improvements at 29 locks on the Upper Mississippi River and 8 locks on the Illinois Waterway and the impacts of providing these improvements. More specifically, the principal problem being addressed is the potential for significant traffic delays on the system within the 50-year planning horizon, resulting in economic losses to the Nation. The study will determine whether navigation improvements are justified, and, if so, the appropriate navigation improvements, sites, and sequencing for the 50-year planning horizon. The feasibility study also includes the preparation of a system Environmental Impact Statement (EIS).
The goal of this interim report is to summarize the entire process of identifying and screening the small-scale measures, leading up to the selection of a final set for use along with large-scale measures in developing alternative plans.
However, the final product of the System Navigation Study is the feasibility report, which will constitute the decision document for processing to Congress.
Small-scale measures are navigation improvements of smaller scope than constructing a new lock or extending the existing lock chamber. The process first identified a universe of 92 potential small-scale measures that might improve system efficiency. The items were then qualitatively screened to select those measures most suitable for further detailed analysis. The first two steps are presented in greater detail in the *General Assessment of Small Scale Measures* report dated June 1995. Following the selection a smaller group of the most promising measures, the *Detailed Assessment of Small Scale Measures (*December 1998) was conducted to quantify the costs, performance, and impacts of the measures. The additional information provided the necessary details for a final secondary screening summarized in this report. The five measures remaining after this screening (guidewall extensions with powered kevels, switchboats with guidewall extensions, congestion tolls/lockage time charges, mooring facilities, and approach channel improvements) will be incorporated into the systemic analysis for use in developing alternative plans and the final evaluation and comparison of costs, benefits, and impacts.

28. U.S. Congressional Budget Office, ***Paying for Highways, Airways, and Waterways: How Can Users Be Charged?,*** May 1992, Congress of the United States, Washington, D.C.
The methods of financing highways, airways, and waterways influence both the amount of revenue that can be raised and the efficient allocation of resources. The concept of revenue adequacy—whether revenues cover costs—is important to the cash-strapped federal government, but it also has implication for efficient allocation of resources in the long run. If the costs of an investment project cannot be recovered from those who use it, the project's feasibility comes into question. But an investment that benefits society is worth making, even though it may not be possible to charge users for it. This often characterizes goods and services provided by the federal government, and it underlies the rationale for government rather than the private activity in certain sectors. Revenue adequacy can provide information about the demand by users for public investments, but it alone cannot be the criterion upon which investment decisions are made.

29. U.S. General Accounting Office, ***Factors to be Considered in Setting Future Policy for Use of Inland Waterways***, 1975, Report to the Congress by the Comptroller General of the US, Washington, D.C., 58 pages.
This report presents factors which the Congress will need to consider in establishing a national policy for funding inland waterways improvements and operations and in considering proposals for imposition of waterways user charges.

30. Wei CH, Dai MDM and Schonfeld PM, **Computational Characteristics of a Numerical Model for Series of Waterway Queues**, *Transportation Research Record 1333*, 1992, pp. 45-54
A numerical method has been developed for estimating delays on congested waterways represented by series of G/G/1 queues (i.e., with generally distributed arrival and service times and one chamber per lock). It is based on a metamodeling approach that develops simple formulas to approximate the results of simulation models. The functional form of the metamodels is derived from queueing theory, whereas their coefficients are statistically estimated from simulation results. The algorithm scans along a waterway and sequentially estimates at each lock the arrival distributions, departure distributions, and delays. It can be applied to systems with two-way traffic through common bidirectional servers as well as to one-way traffic systems. Computational results are presented to illustrate the speed and convergence properties of the algorithm and to investigate some of its variants. The algorithm works satisfactorily and flexibly with different convergence criteria and scanning processes. For an illustrative 20-lock system, parameter estimates converge with five iterations and less than 3 sec of CPU time to differences lower than 0.1% between successive iterations. The computation time increases only linearly with the number of locks in the system, thus allowing the analysis of very large systems of interdependent queues.