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Authors of the Papers in This Record

Barker, Bruce, Division of Water Resources, Illinois Department of Transportation, 2300 South Dirksen Parkway, Springfield, IL 62764
Bronzini, Michael S., Transportation Center, University of Tennessee, Knoxville, TN 37916
Campbell, E. Wilson, Planning Division, New York State Department of Transportation, 1220 Washington Avenue, Albany, NY 12232
Cohen, Gerald S., Planning Division, New York State Department of Transportation, 1220 Washington Avenue, Albany, NY 12232
Eastman, Samuel Ewer, Economic Sciences Corporation, 4226½ River Road, N.W., Washington, DC 20016
Forstall, Keith W., Multisystems, Inc., 1050 Massachusetts Avenue, Cambridge, MA 02138
Gooding, David I., Planning Division, New York State Department of Transportation, 1220 Washington Avenue, Albany, NY 12232
Hawnn, Arthur F., Institute for Water Resources, U.S. Army Corps of Engineers, Kingman Building, Fort Belvoir, VA 22060
Hochstein, Anatoly, Louis Berger and Associates, Inc., 100 Halsted Street, East Orange, NJ 07019
Margiotta, Richard A., Transportation Center, University of Tennessee, Knoxville, TN 37916
McEvoy, Frank A., 250 Melwood Avenue, Pittsburgh, PA 12513; formerly with New York State Department of Transportation
Sharp, Francis M., Institute for Water Resources, U.S. Army Corps of Engineers, Kingman Building, Fort Belvoir, VA 22060
Stammer, Robert E., Jr., Department of Civil and Environmental Engineering, Vanderbilt University, Box 90, Station B, Nashville, TN 37235
Young, G. Frederick, Planning Division, New York State Department of Transportation, 1220 Washington Avenue, Albany, NY 12232
Zabaloieff, Ivan, Louis Berger and Associates, Inc., 100 Halsted Street, East Orange, NJ 07019

Inventory of Potential Structural and Nonstructural Alternatives for Increasing Navigation Capacity of the Upper Mississippi River System

ANATOLY HOCHSTEIN, BRUCE BARKER, AND IVAN ZABALOIEFF

Innovative design, operational changes, or relatively low-cost structural modifications may eliminate constraints at existing locks and, as a result, lock replacement or other major capital investments to increase waterway carrying capacity can be significantly postponed while still providing adequate capacity. The relief of constraints to navigation and corresponding capacity improvements, however, represent a complex area of waterway analysis that requires combined analytic expertise in the disciplines of hydraulic, hydrologic, and structural engineering; operations research; naval architecture; and economics. The primary elements of water transportation, including lock facilities, channel design, and maintenance and tow fleet operations, are not isolated factors that can be treated separately but are integrated parts of a complex system. About 40 different improvement measures to improve waterway capacity have been analyzed. These measures are grouped as follows: scheduling of lock operations (assistance to multicut lockages), improvements to approaches, modification of tow configuration and operation pattern, and lock operating controls and minor structural actions to correct design deficiency. Each measure is evaluated based on its history of application, cost, and impact on capacity. The most promising measures were found to be lockage scheduling ("N-up/N-down" policy), the use of helper boats, the modification of tow haulage equipment, and the use of bow thrusters. As a result of the assessment of the impact of individual measures and combinations of measures (scenarios) on lock performance, specific input variables for capacity determinations are presented. These key input variables were used in the lock capacity model to simulate future transportation development of the Upper Mississippi waterway system.

This paper reports on a contract study of navigation capacity improvements completed in April 1981 for the Upper Mississippi River Basin Commission. The Commission had been directed by Congress to prepare a master management plan for the Upper Mississippi River System (UMRS) by January 1, 1982. The system consists of the Mississippi River between Cairo, Illinois, and St. Paul, Minnesota; the Illinois Waterway; and the navigable portions of the Minnesota, St. Croix, Black, and Kaskaskia Rivers (see Figure 1).

All master-plan studies pertaining to navigation capacity improvements on the system, economic evaluation of these improvements, and analysis of related transportation impacts were assigned to the Navigation-Transportation Work Team. The work-team members represented the U.S. Army Corps of Engineers, the U.S. Department of Transportation, the U.S. Maritime Administration, the departments of transportation of five states, and four public members.

This was the earliest contract study of the work team, since an inventory of structural and nonstructural capacity improvement measures would provide the essential building blocks for navigation capacity expansion plans. Beyond a few site-specific studies, conducted by the Corps of Engineers, no systemwide inventory existed.

Building additional locks is, of course, the best-known means for increasing the capacity of canalized waterways. But it is also the most expensive means. For this reason, the work team desired an imaginative and exhaustive search for less capital-intensive but effective measures. These are often styled "nonstructural" measures but really encompass structural modifications, equipment improvements, operational improvements, towing equipment improvements, and even increases in lock staffing and towboat crewing. The study scope also included anything that could reduce haulage cost and facilitate traffic movements, especially at congested locks. The contractor's proposal responded very well to this objective.

Of course, the study results would determine the success of the work team's navigation capacity expansion planning, or its failure if significantly effective measures were overlooked. In addition, the array of measures had to serve three planning objectives dictated by master-plan study requirements:

1. Full range of system capacities--A number of system capacity improvement schemes would be constructed to explore the full range of capacity up to "unconstrained" waterway traffic projections. It was hoped that this range would at least include one scheme yielding the greatest net economic benefits. It would provide a range of potential future traffic densities needed for impact studies to be done by the Environmental Studies Work Team. Finally, it would provide a range of traffic diversions needed for intermodal impact studies.
2. Primarily nonstructural scheme--Several system capacity improvement schemes would use only nonstructural measures--that is, no additional locks. The best of these would satisfy a Water Resources Council planning requirement for an alternative plan that makes maximum feasible use of nonstructural measures.
3. Second lock at Alton--Congress explicitly requested information on a second lock at the new Locks and Dam 26 under construction at Alton, Illinois. When is a second lock needed and economically justified? What size should it be--110x600 ft or 110x1200 ft?

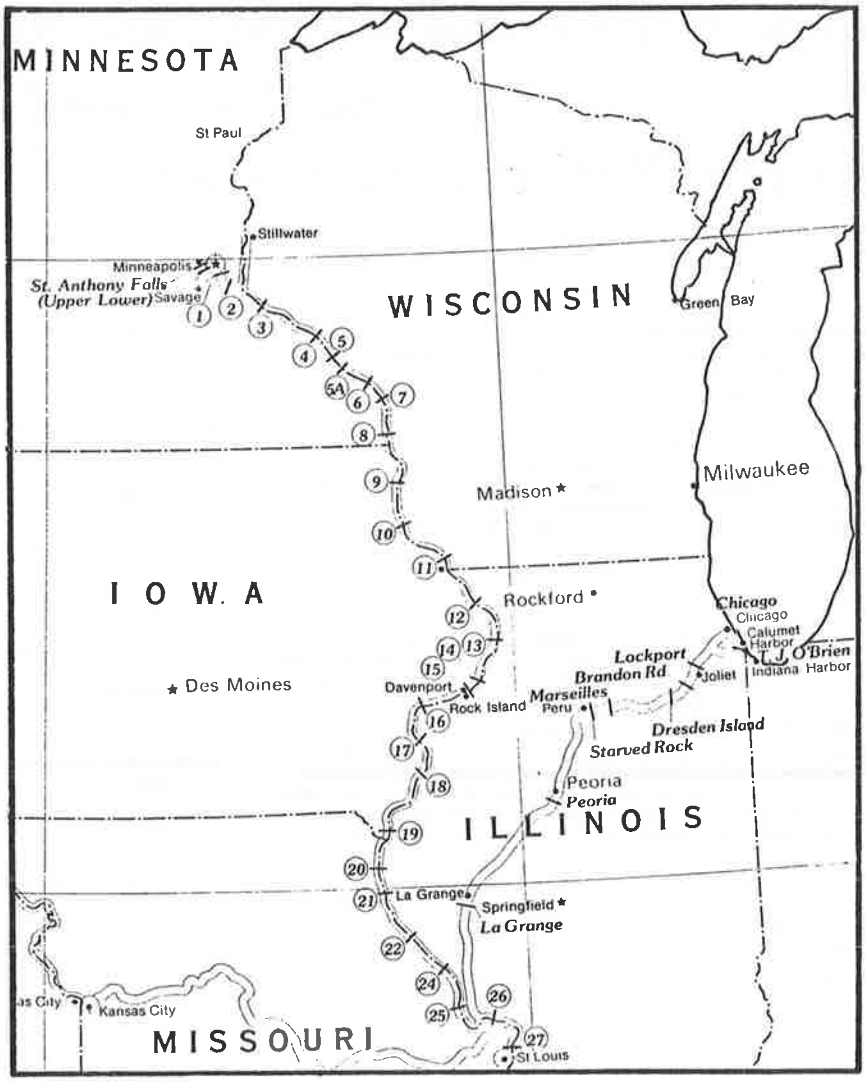
Finally, study results had to be organized and presented to immediately serve as input to the work team's planning and evaluation studies. Narrative, tabular, and map presentations were required to describe where a measure could be used--for example, at which locks, how it works, and how it is implemented. Capital, operation, maintenance, repair, and annualized costs were required for economic evaluation. Performance data on lock processes and component lockage times had to be presented in the exact form required for data input to a lock simulation model.

MEASUREMENT OF CAPACITY AND PERFORMANCE

The capacity of a canalized waterway system is essentially limited by locks, especially the most congested locks. For this reason and other study constraints, the work team decided not to develop a model capable of simulating tow movements throughout the system. Instead, it concentrated on improving a lockage simulation model, which became LOKSIM2.

Model development proceeded concurrently with this contract study and was completed at the same time. Then the performance data for measures selected by the work team were analyzed with the model to produce lockage delay functions. This unfortu-

Figure 1. Upper Mississippi River Basin system.



nate but unavoidable timing of work created special difficulties for the contractor and the work team:

1. The contractor had to evaluate the capacity effectiveness of measures and combinations of measures without benefit of the most sophisticated tool, the LOKSIM2 model.
2. The work team had to screen, discard, and select measures to a large degree before they were fully evaluated.

The solution was to quantify the effectiveness of measures, for interim purposes, by calculating the change in lock tonnage capacity. This was done by using a lock capacity formula the contractor had developed for the National Waterways Study that consists of the following equations for capacity (C) and service time (T):

$$C = \left(\prod_{i=1}^{3} Ki \right) NLT_s/T \qquad (1)$$

and

$$T = T_f + f_d\,(T_t + D) + f_s S \qquad (2)$$

where

Ki = three reduction coefficients for empty backhaul, recreation or downtime, and seasonality;
N = time frame under consideration (month or year);
L = barge lading (tons/barge);
T_s = tow size (barges);
T_f = fly/exchange lockage time;
T_t = turnback lockage time;
D = extra time for double lockages;
S = extra time for setover lockages;
f_d = frequency of double lockages; and
f_s = frequency of setover lockages.

This formula estimates one point, very high, on the lockage delay function. Cargo throughput at this point is called "capacity". As can be seen from the formula, this calculated capacity is directly proportional to tons per tow and inversely proportional to average lockage time. The lock processes and process time components are closely related to those used in the LOKSIM2 model and the Performance Monitoring System (PMS) data base.

Since neither the calculated capacity nor the absolute value of change in capacity was particularly useful to the work team, the formula was used to calculate an index. The chosen index was percentage increase in capacity (PIC), which could readily separate measures with great effect from those with little effect.

Table 1. Average 1976 PMS data.

	Lockage										Fleet			
	Time (min)													
	Approach				Exit		Frequency		Extra Time					
Lock	Fly/ Exchange	Turnback	Entry	Chambering	Fly/ Exchange	Turnback	Setovers	Doubles	Setovers	Doubles	Avg Tow Size (no. of barges)	Barge Lading (tons)	Frequency of Loaded Barges	Seasonal Factor
Upper Saint Anthony	3.5	3.0	4.0	9.0	3.5	3.5	0.65	-	5.0	-	1.67	1337	0.50	0.52
Lower Saint Anthony	5.0	5.0	4.5	12.0	2.0	2.5	0.69	-	7.0	-	1.79	1252	0.50	0.56
1	4.5	3.5	5.0	14.0	4.5	4.5	0.66	0.03	6.5	15.5	1.81	1271	0.50	0.56
2	13.0	7.0	6.5	10.5	4.5	5.5	0.14	0.41	23.0	20.5	6.97	1488	0.60	0.70
3	10.5	5.5	5.0	7.0	5.0	5.5	0.15	0.52	23.0	20.5	7.66	1502	0.64	0.65
4	12.5	4.5	5.5	7.0	5.0	5.0	0.13	0.53	23.0	20.5	8.08	1523	0.65	0.66
5	12.0	4.0	5.5	8.0	5.0	5.0	0.14	0.54	23.0	20.5	8.09	1502	0.67	0.67
5A	10.5	3.5	5.0	7.5	6.0	5.5	0.15	0.58	23.0	20.5	8.09	1513	0.67	0.67
6	14.0	4.0	5.5	7.0	4.5	6.5	0.13	0.56	23.0	20.5	8.30	1507	0.67	0.67
7	12.5	4.5	6.5	6.5	5.5	5.5	0.11	0.58	23.0	20.5	8.28	1504	0.67	0.65
8	12.0	5.0	5.5	9.0	7.5	6.5	0.14	0.57	23.0	20.5	8.35	1505	0.67	0.66
9	12.0	4.5	6.0	7.5	6.0	6.0	0.15	0.59	23.0	20.5	8.52	1499	0.70	0.66
10	11.0	4.0	5.5	8.0	5.0	5.5	0.10	0.58	23.0	20.5	8.30	1497	0.70	0.66
11	14.5	4.0	5.0	10.5	6.0	5.0	0.11	0.58	23.0	20.5	8.35	1487	0.70	0.66
12	16.0	6.5	5.0	7.5	5.5	5.5	0.13	0.60	23.0	20.5	8.83	1480	0.71	0.65
13	10.5	3.0	5.5	9.0	6.0	6.0	0.13	0.60	23.0	20.5	8.78	1482	0.71	0.66
14	9.0	4.5	4.0	8.5	4.5	4.5	0.09	0.45	23.0	20.5	7.52	1391	0.69	0.68
15	13.5	5.0	4.5	11.5	7.0	6.5	0.14	0.49	23.0	20.5	7.57	1495	0.71	0.67
16	9.0	3.0	4.5	9.0	10.0	4.5	0.14	0.48	23.0	20.5	7.39	1494	0.70	0.68
17	20.0	6.0	5.0	8.0	8.0	5.0	0.14	0.54	23.0	20.5	8.12	1487	0.69	0.67
18	13.5	4.0	6.0	9.0	5.0	5.0	0.15	0.56	23.0	20.5	8.30	1465	0.69	0.67
19	19.0	9.0	8.0	21.0	11.5	9.5	-	-	-	-	8.81	1479	0.68	0.69
20	15.0	4.0	5.0	8.0	7.0	5.5	0.14	0.62	23.0	20.5	9.08	1475	0.68	0.69
21	18.5	6.5	5.0	8.0	6.0	5.0	0.14	0.61	23.0	20.5	9.17	1475	0.68	0.69
22	26.5	9.0	6.0	8.5	13.0	5.5	0.15	0.62	23.0	20.5	9.21	1478	0.68	0.71
24	18.5	5.0	5.0	10.5	7.0	6.0	0.18	0.58	23.0	20.5	8.86	1487	0.66	0.72
25	20.0	5.0	4.5	10.0	3.5	3.5	0.17	0.58	23.0	20.5	8.91	1489	0.66	0.72
26														
Main chamber	24.0	2.0	6.5	14.0	9.0	7.0	0.16	0.72	23.0	20.5	10.40	1457	0.65	0.85
Auxiliary chamber	18.0	5.5	2.0	13.5	4.0	3.0	0.15	0.48	23.0	20.5	3.53	1329	0.52	0.85
27														
Main chamber	14.5	4.0	8.5	12.0	8.5	7.5	-	-	-	-	8.62	1513	0.69	0.85
Auxiliary chamber	13.5	3.0	5.0	9.5	4.5	4.0	0.17/0.05	0.53/0.28	23.0	20.5	2.91/ 6.5	1480	0.46	0.85
T. J. O'Brien	3.0	2.5	3.0	11.5	3.0	3.0	-	-	-	-	2.19	1212	0.61	0.82
Lockport	10.0	4.5	5.0	21.0	7.0	4.0	0.51	0.10	23.0	20.5	5.24	1511	0.59	0.77
Brandon Road	15.5	7.0	5.0	19.0	8.0	5.0	0.36	0.26	23.0	20.5	5.99	1449	0.60	0.80
Dresden Island	12.5	5.0	4.5	16.5	5.0	4.0	0.32	0.28	23.0	20.5	6.04	1527	0.61	0.87
Marseilles	13.5	5.5	5.5	20.0	9.0	4.0	0.30	0.29	23.0	20.5	5.87	1543	0.61	0.83
Starved Rock	13.0	7.0	5.0	13.5	6.5	4.0	0.30	0.32	23.0	20.5	6.18	1532	0.61	0.91
Peoria	13.5	5.0	6.5	11.0	7.5	6.0	0.29	0.41	23.0	20.5	6.95	1507	0.61	0.91
LaGrange	17.5	7.0	6.5	8.0	6.0	6.0	0.24	0.53	23.0	20.5	7.95	1455	0.63	0.91

A cost-effectiveness index was then derived by dividing PIC by the annualized cost in thousands of dollars. The highest values of this index were associated with very inexpensive measures that produced some, albeit small, increase in capacity. As expected, high-capacity locks were observed to have moderately low cost-effectiveness indices.

Hindsight gained from the LOKSIM2 evaluations can be summarized as follows:

1. The indices are generally reliable in showing the preference or rank order of closely competing and mutually exclusive measures.
2. The indices are not very reliable in ordering nonexclusive and essentially unrelated measures.
3. The indices tend to exaggerate the utility of measures that are only effective at a very high rate of use.
4. The indices tend to underrate the utility of measures that are effective at a moderate to high rate of use.

Calculated capacities and derived indices are not the best means for measuring the performance of capacity expansion measures. Performance is ultimately measured in economic terms: the transportation cost savings resulting from a measure versus the annual cost of implementing a measure.

Transportation savings for locks result primarily from increasing the service rate of lockages by adding lock chambers, reducing component lockage times, and improving lockage processes (for example, by eliminating double and setover lockages). Other savings could result from reducing recreational lockages by a restrictive policy or eliminating such lockages with a separate recreational lock.

The basic cost reduction information for economic analysis is the shifted delay function that results from a measure or a combination of measures. The delay function is calculated by a lock simulation model. Consequently, the performance of a lock improvement measure must be described quantitatively and accurately in the exact lock processing terms and component lockage times used in the simulation model.

The lock processing terms and component times used in this study are given below:

T_s = average tow size (barges),
L = average barge lading (tons),
K1 = frequency of loaded barges,
K2 = availability factor = 1 - frequency of downtime and recreation,
K3 = seasonality factor = average seasonal tonnage/peak seasonal tonnage,
A_f = fly/exchange approach (min),

Table 2. Selected measures to increase system capacity.

	Quantitative			Qualitative			
Measure	Annualized Cost ($000s)	Cost/PIC ($000s)	PIC[a]	Safety	Operation Versus Investment	General Use	Applicability
Scheduling of lock operations, assistance to multicut lockages							
Institute N-up/N-down policy	0	0	-13 to 16	High	-	Common	Moderate
Provide helper boats	964	60	16	Moderate	Operation	Rare	Wide
Provide switchboats	1420	89	16	Low	Operation	Rare	Limited
Institute ready to serve policy	2092	63	33	Low	Operation	Proposed	Limited
Improve tow haulage equipment	751	27	28	Low	Investment	Proposed	Wide
Increase lock staffing	52	39	1-2	High	Operation	Proposed	Moderate
Institute lock scheduling	9	3	3	High	Operation	Rare	Moderate
Improvements to approaches							
Improvements to approaches	116	39	3	High	Investment	Common	Moderate
Provide adjacent mooring cells	18	14	1-2	High	Investment	Common	Limited
Provide funnel-shaped guidewalls	U	U	U	High	Investment	Proposed	Limited
Install wind deflectors	2-20	25-200	0-0.1	High	Investment	Proposed	Limited
Tow configuration and operations							
Use of regular bow thrusters	U	U	4	High	Investment	Rare	Wide
Use of bowboats	U	U	21	High	Investment	Proposed	Wide
Tow-size standardization	U	U	17	Moderate	Operation	Proposed	Wide
Cooperative scheduling	U	U	13	Moderate	Operation	Proposed	Wide
Waterway traffic management	5-15	3	4	High	Operation	Proposed	Wide
Expand fleeting areas	200	U	U	Moderate	Investment	Common	Limited
Bridge maintenance and operation	U	U	0-5	High	Operation	Common	Wide
Lock operating controls							
Modify intake-outlet structures	70	16	4	Moderate	Investment	Rare	Limited
Install trash racks	29	7	4	Moderate	Investment	Common	Limited
Expedite operations in ice conditions	23	12	2	Moderate	Investment	Common	Wide
Install air bubbler system	38	-	0	High	Operation	Common	Limited
Install floating mooring bitts	14	-	0	High	Operation	Common	Limited
Improve lock operating equipment	191	-	0	High	Investment	Rare	Limited
Install gate wickets	High	-	0-3	Low	Investment	Proposed	Limited
Provide operating guides	Moderate	-	0-3	High	Operation	Proposed	Wide
Centralize controls	104	104	1	High	Investment	Rare	Wide
Provide replaceable fenders	Low	-	0-1	Low	Investment	Proposed	Wide
Clear vessel from filling-emptying system	Low	-	0	High	Investment	Common	Wide
Structural actions							
Reduce interference from recreation	419	65	6	Moderate	Investment	Common	Wide
Improve use of auxiliary chamber	U	U	10-50	Moderate	Operation	Common	Limited
Enlarge locks to 1200 ft	4575	95	48	Low	Investment	Rare	Wide
Physical lock replacement	8950	61	148	High	Investment	Common	Wide

Note: U = unavailable.

[a] Typical range.

A_t = turnback approach (min),
X_f = fly/exchange exit time (min),
X_t = turnback exit time (min),
E = entry time (min),
F = chambering time (min),
$X_{t,1}$ = turnback exit time for first cut (min),
F' = chambering time between cuts (min),
$A_{t,2}$ = turnback approach time (min),
$E2$ = entry time (min),
$F2$ = chambering time (min),
Δ = variation due to impact of a given measure.

Entry time (E) includes breakup time for doubles (7.0 min) and reconfiguration time for setovers (10.0 min); exit time (X_{tf}) includes makeup time for doubles (13.5 min) and reconfiguration time for setovers (13.0 min). Terms A_f through F are used in their given form when the impact in the variables is the same for single, setovers, or doubles. Terms $A_{t,2}$ through F2 are used for the second cut of a double lockage.

A large amount of data on lock processes and component times has been collected by the Corps of Engineers and was compiled for this study. In 1975, as part of a PMS, the Corps instituted a special lockage log form. The Corps has now collected thousands of measured observations of the most common lockage process and component times at locks in the UMRS. Table 1 gives a compilation of some of the data.

ASSESSMENT OF CAPACITY PROBLEMS AND POTENTIAL MEASURES

The development of capacity improvement measures requires an exact understanding of congestion problems in operations and time component terms. The design problem is then to develop a measure that will improve the operations or times. The solution can be approached from either direction.

For example, the work team and the contractor had available numerous proposals for capacity improvements from the National Waterways Study and project- or site-specific studies of Corps of Engineers districts. There is also some literature on European experience. These measures could be costed and analyzed in terms of operations and component times.

The work team provided the contractor the results of a lockmaster survey. Along with technical data on lock design, equipment, and operations, the survey provided opinions on problems at each site. These opinions provided clues to the causes of abnormal time components shown in PMS data. Additional sources of problems and potential solutions included (a) the opinions of masters and pilots and work-team members, (b) interviews with Corps division and district operations personnel, and (c) field reconnaissance of each lock site.

The search produced 43 measures that have some potential for improving the navigational capacity of the system.

Table 3. Helper-boat alternative with N-up/N-down policy.

Lock	Time Reduction			PIC	Annualized Cost ($000s)	Cost/PIC ($000s)
	Doubles ΔX_t	Setovers ΔE	Setovers ΔX_t			
Upper Saint Anthony	-	-	-	-	-	-
Lower Saint Anthony	-	-	-	-	-	-
1	-	-	-	-	-	-
2	13.5	10	13	10.6	991	93
3	13.5	10	13	21.4	966	45
4	13.5	10	13	22.8	960	42
5	13.5	10	13	23.0	976	42
5A	13.5	10	13	26.7	1002	38
6	13.5	10	13	23.1	996	43
7	13.5	10	13	22.7	990	44
8	13.5	10	13	20.0	952	48
9	13.5	10	13	20.5	960	47
10	13.5	10	13	16.8	989	59
11	13.5	10	13	19.9	991	47
12	13.5	10	13	21.2	981	46
13	13.5	10	13	19.9	984	49
14	13.5	10	13	14.9	484	32
15	13.5	10	13	16.2	484	30
16	13.5	10	13	22.2	957	43
17	13.5	10	13	22.0	952	43
18	13.5	10	13	21.5	973	45
19	-	-	-	-	-	-
20	13.5	10	13	21.7	945	44
21	13.5	10	13	20.4	1019	50
22	13.5	10	13	18.2	1047	58
24	13.5	10	13	20.0	1037	52
25	13.5	10	13	21.1	1009	48
26						
Main chamber	13.5	10	13	17.4	1112	64
Auxiliary chamber	13.5	10	13	21.2	1112	53
27						
Main chamber	-	-	-	-	-	-
Auxiliary chamber	13.5	10	13	14.2	1050	74
T. J. O'Brien	-	-	-	-	-	-
Lockport	13.5	10	13	6.4	1030	161
Brandon Road	13.5	10	13	8.9	979	110
Dresden Island	13.5	10	13	8.5	1003	118
Marseilles	13.5	10	13	7.7	975	127
Starved Rock	13.5	10	13	12.6	1010	80
Peoria	13.5	10	13	19.5	942	48
LaGrange	13.5	10	13	23.4	945	40

Screening Measures

The ultimate objective of screening the list of measures was to identify those that are widely applicable and potent in improving system capacity. But most measures required developmental work to perfect performance and cost data. There was a need to concentrate efforts on measures that were judged to have the greatest payoff potential.

Quantitative screening criteria were the capacity and cost-effectiveness indices previously discussed. Qualitative measures included (a) safety effects, rated from low to high; (b) nature of costs, whether capital or operational; (c) use, rated as rare, common, or proposed; and (d) applicability, rated as limited, moderate, or wide.

The criteria were applied to all measures based on available information and were provided to the work team. Using its collective judgment, the work team grouped the measures into three study priorities and one group not to be studied.

Following development work, all of the refined performance and cost data were presented for further screening. This information is presented in Table 2.

Development and Evaluation of Measures

The development and evaluation of measures represented the major work effort of the study. Prior to this stage, many measures were no more than ideas and needed considerable original evaluation for further screening.

Development included the design of features needed to make the measure operational and to adapt it to lock and dam sites. Measure operations were perfected to best enhance overall lockage operations. Specific sites were identified where the measure was applicable as well as potentially useful. Cost estimates (investment, operation, and annualized) were prepared for each measure on a site-specific basis.

The performance data needed for the lock simulation model were then estimated for each site in terms of time reductions from the PMS average times. Table 3 gives an example of how performance, cost, and capacity indices were compiled.

Applicability and Compatibility of Measures

Additional locks can usually be sited to minimize interference with existing locks. Consequently, they are always a compatible measure making a great, net contribution to capacity. But this is not the case with the so-called nonstructural measures.

Some nonstructural measures are mutually exclusive. The prime example is four potent measures to expedite double lockages: bowboats, helper boats, switchboats, and powered traveling kevels. Some measures can worsen performance at certain sites. For example, an "N-up/N-down" service order is only productive where chambering time is low relative to approach times. But hydraulic improvements that reduce chambering time enhance N-up/N-down.

The important point is that the merits of a particular measure are not properly seen when it is used alone. Rather, good combinations must be found. One good combination (or order of improvement) is to reduce chambering time, which enhances the impact of N-up/N-down service order, which finally enhances the impact of helper boats or traveling kevels. A poor combination is to improve approach times where these are already low relative to chambering time. This tends to preclude the use of helper boats or traveling kevels and to encourage the use of switchboats, which constitute the most expensive and least effective double lockage measure. Moreover, the approach improvements do not help a switchboat operation very much.

The importance of combining measures had not been fully recognized in the past. So the proper combinations found in the study process were extremely valuable. Figure 2 shows the results of testing combinations at an Illinois Waterway lock.

COMPOSITION OF CAPACITY IMPROVEMENT SCHEMES

The next task was to compose capacity improvement schemes by using the developed capacity improvement measures. These schemes were called "scenarios", and several objectives to be served by the scenarios were described earlier.

The remaining work was to assemble proper combinations of measures, or actions, by using the knowledge that had been gained. These combinations are presented in Table 4.

Scenario 1 was intended to be a base, or "without project", condition. Therefore, it only includes simple, inexpensive improvements. Scenarios 2 and 3 are alternative candidates for a primarily nonstructural scenario. Scenario 2 uses bowboats, systemwide, as the double lockage measure; scenario 3 uses helper boats, switchboats, or kevels where appropriate. Scenario 4 adds additional locks to scenario 3 to provide a combined structural-nonstructural scheme. Scenario 5 is primarily a structural scheme, since the potent double lockage measures are eliminated.

Any scheme can be improved through repetitive

Figure 2. Sequencing of actions and alternative scenarios for Marseilles Lock (Illinois River).

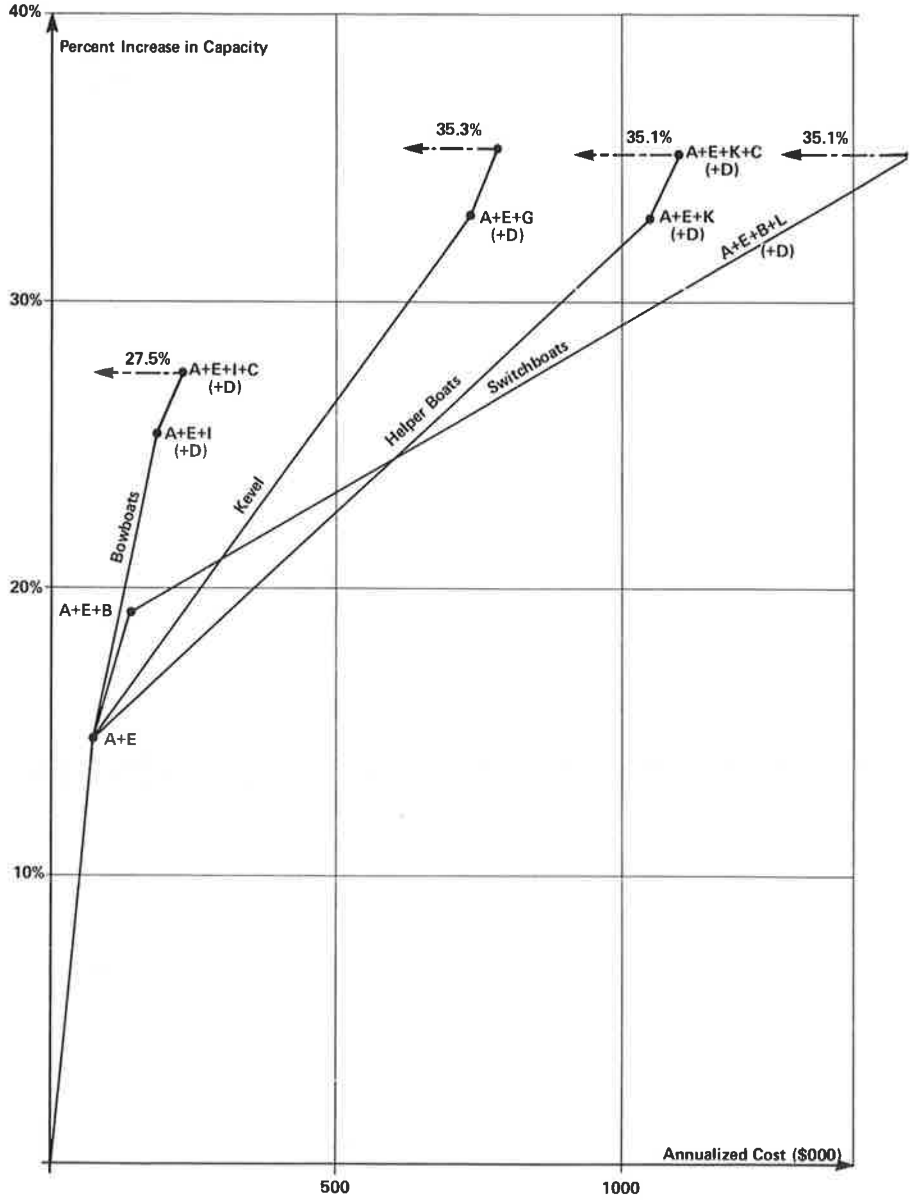


Table 4. Action scenarios.

Action	Description	Scenario 1	2	3A	3B	4A	4B	5
	Government							
A	Correct design deficiencies							
1	<$20 000/PIC	•	•					
2	<$50 000/PIC			•	•	•	•	•
B	Improve approaches							
1	<$20 000/PIC		•					
2	<$50 000/PIC			•	•	•	•	•
C	Increase lock staffing							
1	<$20 000/PIC		•					
2	<$50 000/PIC			•	•	•	•	•
D	Institute N-up/N-down where appropriate	•	•	•	•	•	•	•
E	Expedite operations in ice conditions			•	•	•	•	•
F	Recreational locks, locks 2-11			•	•	•	•	•
G	Traveling kevel as alternative to helper boats				•		•	
H	Build locks							
1	Maximum of one 1200-ft lock/year					•	•	
2	Build 1200-ft locks							•
	Industry							
I	Mandate bowboats for large tows		•					
J	Mandate minimum crew on deck		•					
K	Helper boats where appropriate			•		•		
L	Switchboats where appropriate			•	•	•	•	

trials and economic evaluations. Unfortunately, the deadline for the UMRS master plan did not permit this. Once the scenarios were prepared, there was just enough time to evaluate them.

CONCLUSIONS

This study provided the imaginative and exhaustive search for improvement measures desired. Knowledge of useful nonstructural measures has been expanded. Certainly these measures should be considered in future navigation planning studies, but planners should be cautious in generalizing the results.

One should not assume hydraulic inefficiencies or approach problems where none exist. Double lockage measures are useless where there are no double-lockage-sized tows. There is no substitute for starting with reliable, quantitative data on performance: PMS, surveys, interviews, and on-site investigations. Solutions must be tailored to the problems. Good combinations of measures must be found. The greatest time and effort should go into developing the best ideas.

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Analysis of Lock Capacity by Simulation

MICHAEL S. BRONZINI AND RICHARD A. MARGIOTTA

LOKSIM2 is a discrete event simulation model developed to analyze the capacity and delay characteristics of single locks on the U.S. inland waterways. Extending previous single-lock simulation techniques, LOKSIM2 features a highly detailed representation of the components of the locking cycle. The model is directly compatible with data provided by the U.S. Army Corps of Engineers Performance Monitoring System. A preprocessor model, TOWLST1, generates tow traffic inputs so as to match distributions of underlying tow characteristics. The output from LOKSIM2 is used to estimate the parameters of a lock delay function. Delay functions obtained for various lock physical and operating conditions can be used to analyze proposed lock improvements.

This paper describes the development and application of a single-lock simulation model, LOKSIM2, used for lock capacity analysis as part of the Upper Mississippi River Master Plan Study. The LOKSIM2 model was developed in response to the need for a method of analysis that could estimate the physical capacity of a single lock under a variety of structural and nonstructural improvement scenarios. Previous single-lock simulators, including LOKSIM (1), LOCALC (2), the lockage routines in the Waterway Analysis Model (3), and SNGLOK (U.S. Army Corps of Engineers, North Central Division), either could not provide the required level of detail or were too cumbersome to use. They did, however, provide the basis for the LOKSIM2 model, which is basically an extension and refinement of these prior modeling efforts. LOKSIM2 is the most detailed model yet created to simulate the operation of a single lock. All input data can be obtained readily from the U.S. Army Corps of Engineers Performance Monitoring System (PMS). The model was programmed in FORTRAN and GASP, a series of FORTRAN-based subroutines that greatly facilitate programming of simulation models (4).

This paper explains the operation of the model, including the structure of inputs and output, and shows how model results are used to estimate lock capacity.

OPERATION OF MODEL

Overview of Lock Operations

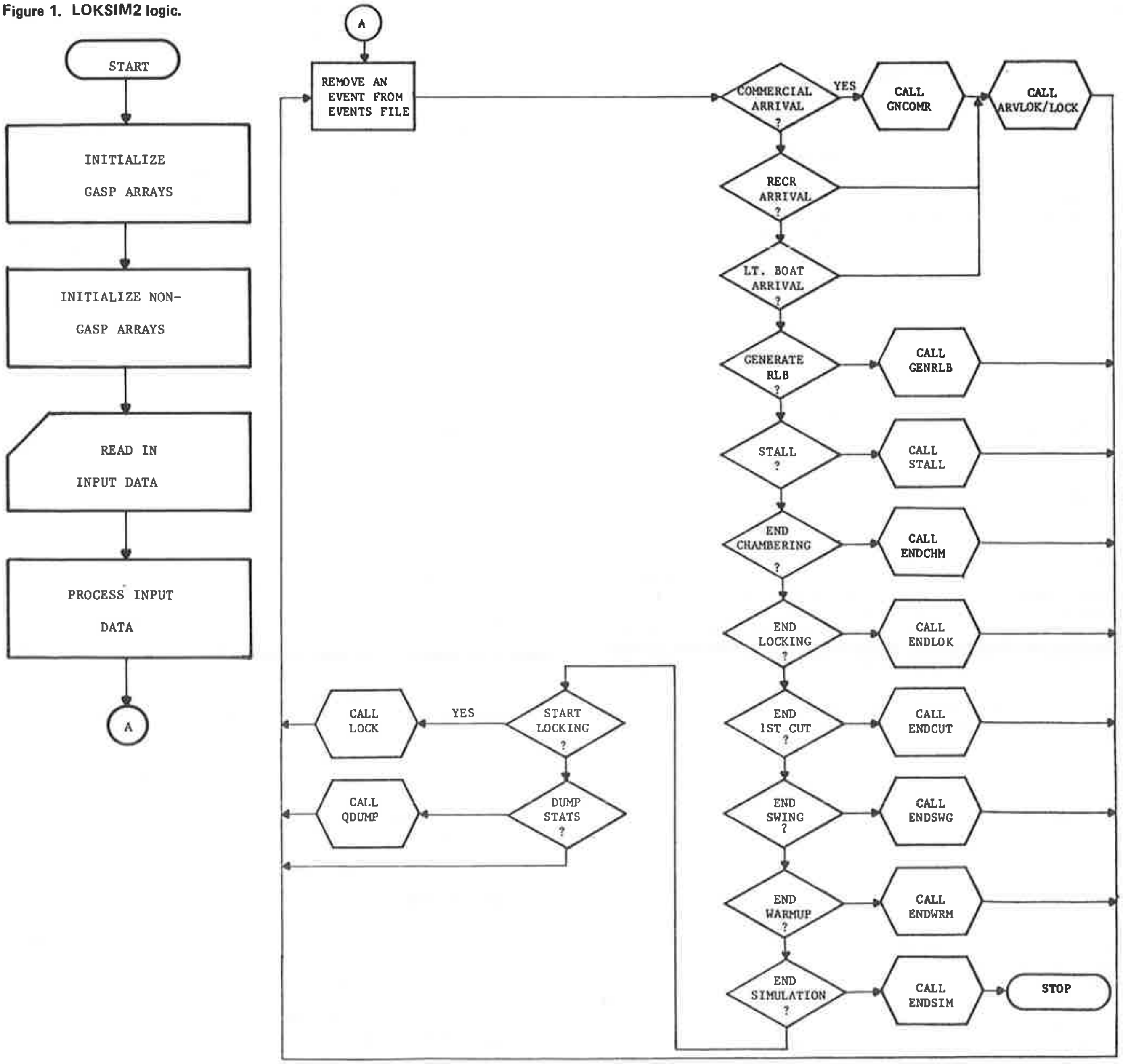
Before a process can be simulated, it is necessary to become acquainted with the details of that process. If more details are accounted for in the simulation, there is a greater likelihood that the results will be realistic. There is, however, a direct relation between amount of detail and cost in terms of development, computer time, and data requirements. Since the objective of this research was to simulate the operation of a single lock, a great degree of complexity could be incorporated into the model. If the purpose had been to simulate an entire system of locks, a less detailed model of lock operations might have been adequate.

Essentially, a lock is a chamber located in or near a dam that can be sealed off and within which the water level can be raised or lowered to meet the water level above or below the dam so that vessels can pass through the dam. Vessels that use locks fall into three categories: (a) commercial tows, which are made up of one or more barges propelled by a towboat; (b) recreational craft, which are noncommercial pleasure boats; (c) light boats, which are towboats traveling without barges. Most lock time is normally devoted to servicing commercial tows.

Because lock chambers and tows come in various sizes and configurations, there are several types of lockages that may occur. A single lockage takes place if the entire tow can fit into the lock as is. A setover lockage occurs if the configuration of a tow must be changed to fit the chamber size but all of it fits into the chamber when it is reassembled (thus, single and setover lockages require only one flooding or evacuation of the chamber). Double lockages occur when the tow is too large to be locked through on one pass; in such a case, some barges go through, the chamber is returned to the starting level, and the remaining barges and towboat are locked through. Recreational craft and light boats (referred to henceforth as RLBs) can be locked through with a tow if there is room left in the chamber, or they can be locked through by themselves or with more RLBs. It is also possible to subdivide single, setover, and double lockages into more specific types if necessary. In addition, on some of the less active waterways, locks can be so limited in size that only a small number of barges (sometimes only one) can be locked through at a time so that triple, quadruple, or quintuple lockages are required. Because this study covered only the Upper Mississippi River system, where all locks (except one) are at least 110 ft wide and 600 ft long, these latter types of lockages did not have to be considered.

The operation of locks is governed by a set of

Figure 1. LOKSIM2 logic.



preestablished policies designed either to gain better use or to favor one type of craft over another--for example, commercial over RLBs. The so-called "N-up/N-down" policy is the most widely used. This dictates that N tows be served consecutively in one direction and then an equal number in the opposite direction. Other operating policy elements (either stated or followed in practice) include the maximum amount of time the chamber will be held at its current water level in order to service an approaching tow, the maximum amount of time chambering can be delayed in order to fit another vessel in the chamber, the minimum time a recreational craft must wait for lockage, the minimum number of recreational craft that can obtain lockage, and the maximum amount of time that recreational craft must wait for service.

Methodology

The LOKSIM2 analytic procedures are outlined in flowchart form in Figure 1. The figure is incomplete in that the details of all subroutine procedures are not outlined. It does, however, present an overview of the logic of the model. Operations performed by the various program routines are described briefly below.

Read in Input Data

LOKSIM2 requires, among other things, a time-ordered listing of tows to be locked through. This list is provided by use of a preprocessor, TOWLST1, specifically developed for this purpose (the operations of TOWLST1 are discussed later in this paper). The characteristics given for each tow on the list include tow number, arrival time, direction, number of loaded and empty barges of each of three types (jumbo, integrated, and mixed), tons of cargo, and generalized lockage type to occur (single, setover, or double). Other inputs to LOKSIM2 include the following:

1. Lengths of the warm-up and simulation periods;
2. Weekly number of RLBs arriving in each direction;
3. Arrival pattern of RLBs, determined by splitting each day of the week into user-specified intervals and designating the percentage of RLBs arriving during these intervals;
4. Number of recreational craft equal in size to a jumbo barge;
5. Operating policies in effect at the lock;
6. Probabilities that certain specialized lockage types (such as multivessel lockages) will actually occur whenever they are possible;
7. Number of jumbo, integrated, and mixed barges that can fit into the lock chamber;
8. Length and width of the lock;
9. Information on stalls (lock down time); and
10. Locking time distributions for 41 components of locking time, input as either constant, uniform, exponential, truncated normal, or empirical distributions.

Process Input Data

Information in the data is first checked for reasonableness. If it is unrealistic, an error message is printed and the program is terminated; otherwise, it is stored in the proper arrays. Certain events are also scheduled, including the time the warm-up begins and ends, the time the simulation ends, the first upbound and downbound commercial arrivals, the initial time to generate RLB events, and the first stall event.

Remove Event from Events File

For this simulation, events are removed in succession according to their assigned time. Based on what type of event is scheduled, the program takes appropriate action.

Call GNCOMR/Call ARVLOK

If the event is a commercial tow arrival, LOKSIM2 first schedules the arrival event for the next tow in the same direction as the current one (subroutine GNCOMR). If the event is an RLB arrival, this step is skipped. Subroutine ARVLOK then determines whether the vessel should be queued or whether it should be assigned to the lock. If it is assigned, the vessel is locked through via subroutine LOCK.

Call GENRLB

The GENRLB subroutine is called to generate RLB arrivals for the period that begins one hour after the current simulation time. First, however, it schedules an event signaling the next generation time--i.e., the time in the future at which it is again called.

Call STALL

The next stall event is scheduled via a Poisson process, and the length of the current stall is calculated (this is added to the simulation time in the next locking procedure that occurs).

Call ENDCHM

Whenever a vessel (recreational or commercial) is beginning the exit process for the last cut of its lockage, ENDCHM is called to determine the type of exit based on (a) whether the lockage was a single, setover, or double and (b) the locking policies. It then schedules an ENDLOK event at the current simulation time plus the sum of the exit times and stores the time at which the lock will be available again.

Call ENDLOK

Subroutine ENDLOK is called to examine the queues in both directions to ensure that the specified operating policies are adhered to. If necessary, it will call LOCK to perform any necessary lockages. For example, if any recreational craft have waited the user-specified maximum time, they will be locked through.

Call ENDCUT

The ENDCUT subroutine handles the end of the first cut of a double lockage and, if possible and permitted, will process a single lockage or an RLB in the opposite direction of the double between the two cuts. It then schedules an ENDSWG operation.

Call ENDSWG

Subroutine ENDSWG is called at the end of each swing operation that takes place between the cuts of a double lockage. It moves the second cut of the double lockage into the lock, checks to see whether there is room left in the chamber for any RLBs, obtains the chambering time for the second cut, and schedules an ENDCHM event at the appropriate time.

Call ENDWRM

If the chosen event denotes that the end of the warm-up period has been reached, ENDWRM will zero out accumulated statistics, write out summary warm-up queueing statistics, and schedule a queueing statistics dump at the end of each day.

Call ENDSIM

Subroutine ENDSIM is called to dump the accumulated queuing statistics at the end of the simulation time. The program is then terminated.

Call LOCK

Subroutine LOCK is the core of the LOKSIM2 program. It is called whenever a vessel or vessels require lockage. LOCK distinguishes recreational craft, light boats, and commercial tows as well as single, setover, and double lockages. It will also load into the chamber any other vessels that are in queue or that will arrive within a user-specified amount of time, if there is room. LOCK also performs the valuable function of calculating delay for each vessel as well as cumulative delays. LOCK then schedules either an ENDCHM event if the lockage was single, setover, or RLB or an ENDCUT event if the lockage was double.

Call QDUMP

QDUMP is called to dump queuing statistics at the end of each day. It also schedules the next dump in 24 hours from the current simulation time.

Example

An example will serve to clarify the steps outlined above. Suppose the event chosen from the events file indicates a commercial tow. First, the next commercial arrival in the same direction is scheduled via GNCOMR. ARVLOK then either assigns the lock to the tow or queues it if the lock is busy. If assigned, subroutine LOCK is called to process the tow up to its exit. If the lockage is a double, LOCK schedules an ENDCUT event; otherwise, an ENDCHM event is scheduled (both of these events are scheduled at whatever the simulation time is after LOCK has performed its function). Control is then transferred back to the point where another event is removed from the events list. If the next event shows a vessel arriving during the time the current vessel was being processed, it is queued by the appropriate routines. When the event previously scheduled by LOCK is chosen, if the lockage is a double, control is branched to ENDCUT, where the tow is further processed and an ENDSWG event is scheduled. Control is again returned to the top of the loop and branches to ENDSWG. ENDSWG processes the tow and schedules an ENDCHM event, and control is returned to the top again (if the lockage was not a double, ENDCUT and ENDSWG would have been bypassed). ENDCHM then executes and schedules an ENDLOK procedure, and, after another pass through the loop, control is branched to ENDLOK, where operations on this tow are finally completed. All vessels that arrive during the processing of this tow are queued, but some may be locked through with it if conditions permit. However, other nonvessel events (e.g., a stall) can take place during the processing of the tow.

Preprocessor Operations

A separate model was constructed to provide LOKSIM2 with a list of tows of varying characteristics to be locked through. This model, in effect a preprocessor, was named TOWLST1. Essentially, it takes aggregate barge, commodity, and tow data and uses them to create the information necessary for LOKSIM2. TOWLST1 is based on the previous modeling efforts, TOWGEN (5) and LOCALC (2), but has features that are unique to each.

TOWLST1 can be broken down into two basic parts. The first restructures input data into lists and distributions, which are then sampled in the second part to create tows of the required characteristics. Tows are created until one of two situations occurs: (a) the simulation time is exceeded by the assigned arrival time at the lock or (b) the total barge matrix is exhausted.

Read in Input Data

TOWLST1 currently recognizes three barge and/or tow types: jumbo, integrated, and mixed (these were used to be consistent with PMS data). The information required here is as follows:

1. Percentage tow frequencies for tow sizes of 1-18 barges by direction and type;
2. Probabilities that single, setover, and double lockages will occur for each barge type and tow size;
3. Commodity tonnages to move upstream and downstream (eight commodities are currently recognized: coal, petroleum, chemicals, metallic ores, nonmetallic minerals, stone-clay-cement, grain, and "other");
4. Average loadings of the eight commodities in each barge type;
5. Percentages of commodities allocated to the different barge types; and
6. Dedicated equipment percentages for each commodity by barge type.

Convert Tonnages to Loaded Barges

Tonnages are converted to loaded barges as follows:

$$LD_{ibk} = [(ODTONS_{ik} * PCTBRG_{bk})/TNSBRG_{bk}] + 0.5 \quad (1)$$

where

LD_{ibk} = loaded barges of commodity k in barge type b to move in direction i,
$ODTONS_{ik}$ = tons of commodity k to move in direction i,
$PCTBRG_{bk}$ = percentage allocation of commodity k to barge type b,
$TNSBRG_{bk}$ = average loading of commodity k in barge type b, and
0.5 = term added to correctly round to nearest integer.

Calculate Number of Required Empty Barge Movements

Given the number of loaded barges that are required to move the given tonnages, the number of empty barges can be calculated by considering the movements of dedicated equipment and then the number of empty movements needed to balance all barges. The number of empty dedicated equipment barges is found by multiplying the number of loaded barges in the opposite direction by the dedicated equipment percentage:

$$DEDMT_{ibk} = LD_{jbk} * DEDPCT_{bk} + 0.5 \quad (2)$$

where

$DEDMT_{ibk}$ = empty dedicated equipment barges of commodity k and barge type b to move in direction i,
LD_{jbk} = loaded barges of commodity k and barge type b moving in direction j (opposite of i), and
$DEDPCT_{bk}$ = dedicated equipment percentage for commodity k in barge type b.

The empty movements required to balance barges are found by

$$BALMT_{ib} = \max\left[\sum_k (LD_{jbk} + DEDMT_{jbk}) - (LD_{ibk} + DEDMT_{ibk}), 0\right] \quad (3)$$

where $BALMT_{ib}$ is the empty balance movements of barge type b in direction i and j is the direction opposite i. When dedicated equipment percentages are 100 percent, there are no corresponding balanced empty movements.

Calculate Number of Tows of Each Type

To this point, the numbers of loaded and empty barges of each type that must move in each direction have been calculated. The number of tows needed to move these barges is then determined by using information about average tow sizes. Once average tow sizes are computed, the number of tows is found by dividing the total number of barges by the average tow size:

$$TOWMV_{ib} = (SUBTOT_{ib}/AVTSIZ_{ib}) + 0.5 \quad (4)$$

where

$TOWMV_{ib}$ = tows of type b to move in direction i,
$SUBTOT_{ib}$ = total number of barges of type b in direction i
= $\sum_k (LD_{ibk} + DEDMT_{ibk}) + BALMT_{ib}$, and
$AVTSIZ_{ib}$ = average tow size for barge type b in direction i.

Establish Randomized List of Tows of Each Type

The first step in establishing a randomized list of tows by type is to establish a cumulative matrix of the number of tows of each type to move in each direction. Once this matrix is set up, a random number procedure is used to select a cell in the matrix, which results in a random selection of the tow types to appear consecutively in the tow list. This is done for each direction separately.

Establish Cumulative Distribution Function of Tow Sizes

Establishing a cumulative distribution function of tow sizes is a relatively simple procedure that converts tow frequency input data to a cumulative distribution. This is done so that a size can be selected for a tow by sampling with replacement--i.e., by Monte Carlo sampling.

Establish Cumulative Distribution Function of Lockage Types to Occur

LOKSIM2 requires that each tow that arrives at a lock be assigned a generalized lockage type: single, setover, or double. This determination is controlled by the nature of the input data previously discussed. The routine discussed here constructs a cumulative distribution function from the input data so that Monte Carlo sampling can later be accomplished.

Determine Arrival Time at Lock

Tow arrival times are assigned under the assumption that they occur randomly throughout the simulation period and can thus be modeled as a Poisson process. Specifically, the following equation is used:

$$t = (1/\lambda)\log_e [1/1 - F(t)] \tag{5}$$

for $0 \leqslant F(t) \leqslant 1$, where $F(t)$ is the probability that an interdeparture gap $\leqslant t$. λ is defined as the mean tow arrival rate at the lock and is found by dividing the total number of tows by the total simulation time.

To determine the departure time of the ith tow (t_i), TOWLST1 obtains a random number from the random number generator, uses Equation 5 to compute the headway, and then assigns the arrival times as

$$T_i = T_{i-1} + t \tag{6}$$

Select Direction for Tow

Selecting a direction is a simple matter of determining the probability of obtaining one direction over another based on the number of tows, as follows:

$$\text{Prob(up)} = \text{TOWS}_{\text{up}}/(\text{TOWS}_{\text{up}} + \text{TOWS}_{\text{down}}) \tag{7}$$

Once this is established, a random number between 0 and 1 is chosen. If it is less than or equal to Prob(up), the direction is up; otherwise, it is down. Prob(up) is then revised to reflect the fact that a tow of one direction has been removed.

Determine Tow Type

Tow type is determined by using the randomized lists described above. Given the direction, the appropriate list is pointed to and the entries are taken off it in succession. Near the end of the simulation period, one list may become exhausted. In this event the list is reused, starting at the top.

Determine Tow Size

Given direction and type, tow size is selected by randomly sampling the cumulative distribution function established previously. Near the end of the simulation period, a tow size may be selected that exceeds the available number of barges. In this case, tow size is set equal to the number of remaining barges.

Determine Number of Loaded and Empty Barges

TOWLST1 uses the binomial probability distribution to determine the number of loaded and empty barges. This is a discrete distribution suitable for modeling phenomena with two possible outcomes, usually denoted as "success" and "failure". The distribution function is simply a summation of consecutive terms; i.e.,

$$F(x) = \sum_{0}^{x} b(n, p) \tag{8}$$

where $b(n,p) = \binom{n}{x} p^x (1 - p)^{n-x}$.

Given direction and type, TOWLST1 calculates the probability of a "success" (obtaining a loaded barge) as

$$p = \sum_{k} \text{LD}_{ibk}/(\sum_{k} \text{LD}_{ibk} + \text{TOTLMT}_{ib}) \tag{9}$$

where TOTLMT is the sum of dedicated equipment and balance empty barges and where direction i and barge type b have been previously determined by the program.

Next, TOWLST1 samples from b(n,p), where n is equal to the tow size, to determine the number of loaded barges. Empty barges are found by subtraction. The terms in Equation 9 are then revised to reflect the number of loaded and empty barges that remain.

Determine Lockage Type to Occur

TOWLST1 samples the cumulative distribution functions set up previously. Lockage types are found as either single, setover, or double. This determination is based soley on the nature of the input data, which in turn is a function of tow size and type.

Write Tow Characteristics to Tow List for Input to LOKSIM2

As the characteristics of each tow are completed, they are written to a file that is eventually used by LOKSIM2.

Select Characteristics of Next Tow

After writing tow characteristics to the tow list, TOWLST1 loops back to determine the arrival time of the next tow. This loop is continued until one of the two stopping criteria is met.

LOKSIM2 Output

The following statistics are included in the LOKSIM2 output: number of lockages, lockages with hazardous cargo, loaded barges, empty barges, tow size (mean, minimum, maximum), commercial cargo tonnage, and processing time (mean, standard deviation, minimum, maximum). Information on the distribution of delay time is also provided. These outputs are presented separately by direction (up, down, and total) and lockage category (commercial, recreational-light, mixed, and total). A separate table reports the current, mean, standard deviation, and maximum queue length at the end of each day, by direction and lockage category. This is quite useful for identifying infinite queuing situations with unstable traffic and delay statistics.

ESTIMATION OF LOCK CAPACITY

Application of Model to Upper Mississippi River System Locks

For the purposes of this study, the Upper Mississippi system was defined as being those locks on the Mississippi River from Locks and Dam 27 just north of St. Louis, Missouri, upstream to Locks and Dam 1 just south of St. Paul, Minnesota, plus all the locks on the Illinois River. Because it was deemed impractical to analyze the effects of all alternatives at each lock, a series of representative locks was chosen for each river. It was felt that these locks were indicative of the systems at different points. These were Locks and Dams 2, 10, 16, 19, 25, 26, and 27 on the Mississippi and Brandon Road, Starved Rock, and Peoria on the Illinois. The results from these locks were then applied to neighboring locks.

Calibration of the model was carried out first. This basically involved matching generated empty-barge movements to 1976 and 1977 PMS data. Integrated barges were assumed to be 100 percent dedicated--i.e., each loaded-barge movement generates an opposite direction empty-barge movement. Dedicated equipment percentages of the other two barge types were varied until the total empty barges generated produced a ratio of total barges to total kilotons of commodity traffic that matched the ratio shown in PMS (1.00 to 1.10 at most locks). This calibration was performed individually for each lock, and the resulting dedicated equipment percentages were used for all subsequent model runs.

Distributions of lockage component time were estimated by analyzing PMS data for 1976 and 1977. Uniform distributions were used in all cases except for gate operating time and RL8 entry and exit times, where constants were used.

Forecasts of upbound and downbound tonnage by commodity group at each lock for the years 1977, 1990, 2000, 2010, and 2040 were made by the Corps of Engineers. Forecasts for years between these dates were made by using linear interpolation. Since the objective of the analysis was to produce a complete delay curve that captures the relation between average tow delay and annual commodity tonnage throughput, the exact year in which a particular tonnage level is achieved is relatively unimportant. The main use of the forecasts is to preserve the commodity mix expected at the lock at various traffic levels.

The commodity mix also affects the seasonality of traffic demand, which greatly influences capacity and delay. To incorporate the effect of seasonality, each lock was simulated for each of four seasonal months: January, April, July, and October. Each such month represents conditions for an entire season (winter, spring, summer, and fall, respectively), composed of the seasonal month plus the preceding and following months. The portion of the annual tonnage that would appear at the lock during the seasonal month was calculated as follows:

$$\text{Seasonal month tons} = (\text{tons in season}/\text{days in season}) \times \text{days in seasonal month} \qquad (10)$$

Data for this calculation, which consist of monthly tonnage by commodity group, were taken from PMS observations for 1976 and 1977. This method has the advantage of capturing seasonality without giving undue weight to an individual seasonal month. Later in the analysis it was discovered that two periods, peak (April to October) and off-peak (November to January), would work as well as four seasonal months. Peak also assumed a July recreational traffic level, whereas off-peak assumed no recreational traffic. Expansion factors for peak and off-peak periods were calculated in much the same way as those for seasonal months.

Given the above, the model was run under existing conditions for 1977 and 1990. Capacity was estimated for the representative locks by using the method of formulating delay curves presented in the next section of this paper.

It is important to recognize that lock capacity is very sensitive to tow size. Therefore, in this study results were produced at each lock under two tow-size assumptions: (a) the existing tow-size distribution would be maintained and (b) tow sizes would increase significantly over the next 30-50 years.

Formulation of Lock Delay Curves

On completion of the model runs, estimates of annual traffic were made, and estimates of annual delay were obtained by weighting the delay in each period by the ratio of tows in that period to total tows. The example given in Table 1 clarifies these procedures. From Table 1, annual traffic = 14 944 kilotons and annual delay = 107 x (2010/2451) + 31 x (441/2451) = 93 min.

The traffic and delay estimates thus arrived at were expressed in the form of the following hyperbolic delay function:

$$d = Dq/(Q - q) \qquad (11)$$

where

d = average tow delay at flow q,
D = average delay at flow $Q/2$,
q = annual lock commodity traffic, and
Q = physical capacity of the lock.

This functional form was selected when sensitivity tests revealed that it produced an excellent fit to the simulation data in the region where flows exceed 50 percent of capacity (i.e., the high-delay region) and an acceptable fit in the low-flow region. This curve also has the essential properties that delay is zero at zero flow and infinite at 100 percent of capacity use and the desirable feature that one of its parameters is the estimated physical lock capacity.

Delay curve parameters Q and D were computed from two data points (q_1, d_1) and (q_2, d_2). It was found that the best results were obtained when (q_1, d_1) was at a traffic level that produced about 50 percent use of the lock and (q_2, d_2) at a traffic level that yielded about 95 percent use. Use, which is defined as the time the lock is busy divided by the total time in the month, is one of the output items from the model. In some cases, interpolation was necessary to find traffic levels that produced 50 and 95 percent use. The equations used to calculate Q and D are

$$Q = \left\{(1 - d_1/d_2)/[1 - (d_1 q_2)/(d_2 q_1)]\right\} q_2 \qquad (12)$$

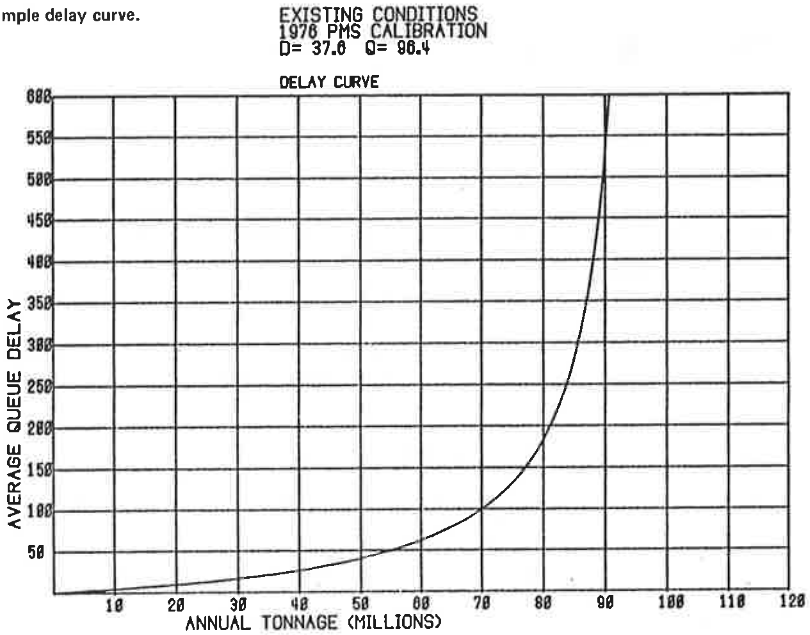
$$D = d_1(Q - q_1)/q_1 = d_2(Q - q_2)/q_2 \qquad (13)$$

Table 1. Procedure for determining annual traffic and annual delay.

Period	No. of Tows	Delay (min)	Kilotons	Expansion Factor	Adjusted Kilotons
Peak	2010	107	2573	5.18	13 328
Off-peak	441	31	592	2.73	1 616
Total	2451				14 944

Note: Expansion factor = days in period ÷ days in seasonal month.

Figure 2. Sample delay curve.



A sample delay curve plot for existing conditions at the new 1200-ft chamber under construction at Locks and Dam 26 is shown in Figure 2. The physical capacity (Q) is 96.4 million tons/year and represents the maximum traffic level that can be supported by the lock, given existing tow sizes and ideal conditions. Because ideal conditions cannot be attained, it is necessary to define operational capacity to be at a level somewhat less than physical capacity. During the course of the study it was found that operational capacity can be estimated by selecting a point on the delay curve beyond which the rise in the curve is essentially vertical. In most cases, this occurs when the flow is 90-95 percent of capacity and average delay is in the range of 7-10 h. This implies that the operational capacity of Locks and Dam 26 under existing conditions (with the existing tow-size distribution) is approximately 92 million tons (95 percent of physical capacity). Of course, other criteria could be used to select operational capacities. The delay curve itself is the important result presented here.

The delay curve method of estimating capacity proved to be an efficient procedure. After calibration verified the applicability of the method, all that was required was to run the model at different traffic levels so that peak runs produced levels of lock use of 50 and 95 percent. Off-peak runs were then made with the same annual commodity flows. Thus, only two points were necessary, each of which consisted of extrapolations that used peak and off-peak runs.

SUMMARY AND CONCLUSIONS

The purpose of this research was to develop and apply methods of estimating the capacity of navigation locks on inland waterways. A detailed simulation model with a variety of user-specified parameters was developed, tested, and applied to locks in the Upper Mississippi River system. Input data can be easily obtained from the Corps of Engineers PMS. Output from this model was then used to generate delay curves from which operational capacities were derived for existing conditions.

A variety of system improvement scenarios were also formulated. These were necessary because future demand for waterway transportation on the Upper Mississippi was projected to be higher than the current system can support. Since the effects of the improvements accrue to various input components of the model, simulation of them was a straightforward process. Delay curves were then developed for each alternative. The curves can be used to estimate the physical and operational capacities and can also be used to determine at what point in time operational capacities are reached, if commodity forecasts are trustworthy. In this way future bottlenecks in the system can be identified so that waterway planners can be provided with the information needed to formulate and analyze various improvement plans.

ACKNOWLEDGMENT

The work reported in this paper was carried out by the University of Tennessee Transportation Center under contract to the North Central Division (NCD) of the U.S. Army Corps of Engineers. Greg Kandl and Don Ward of NCD programmed the LOKSIM2 model and performed numerous analyses of PMS data files to generate model input. Harvey Kurzon of NCD was the technical monitor of the work performed. The assistance of numerous other Corps personnel, particularly in the St. Louis District and the NCD, is gratefully acknowledged.

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Abridgment

Study of Barge Line-Haul Rates

ARTHUR F. HAWNN AND FRANCIS M. SHARP

Waterway rate characteristics are an essential part of benefit analysis of waterway investment. For the first time, waterway rates have been collected and analyzed over the entire Mississippi River and its tributaries as opposed to other studies that covered only a part of that system. The study is most unique in that rates were verified from the actual records kept by the carriers. A total of 1700 rates were stratified based on season, origin-destination pairs, and commodity groups. Simple regression analysis suggests that major commodity groups, such as grains, exhibit respectable regression characteristics. The results of the study would be an input to other major investment studies as well as more complex rate analysis.

Benefit-cost analysis is an essential part of waterway transportation investment decisionmaking. Waterway rate analysis is a major component of benefit calculation. This study is the first attempt to evaluate waterway rate characteristics on the entire Mississippi River and its tributaries. Furthermore, this study is most unique in that "rate data" provided by the carriers were verified from actual carrier records. The data obtained by using this study approach, therefore, are more credible than some data that might have been gathered by telephone.

STUDY PURPOSE

The purpose of this study was to collect and analyze rate data on approximately 1700 actual barge shipments and to do this in a manner that (a) would be statistically valid and (b) could, if necessary, stand up in court proceedings.

PRELIMINARY VISITS

It was recognized that collection of confidential rate data, including verification from actual shipper records, was beyond the industry's experience to date. Thus, careful preliminary contact was made with influential industry groups and companies to explain the purposes of the project. Early contact was made with American Waterway Operators, Inc., and with leading individuals.

These early visits were also important in that the study team gained a clear understanding of industry record-keeping procedures, which would influence the project, and the concern of the industry about confidentiality. Through these discussions, it was possible to work out a data collection procedure that would sufficiently protect confidentiality on the one hand while yielding verified rate data on the other.

DATA COLLECTION VISITS

A number of follow-up trips were required to com-

Table 1. Commodity classes for sample selection.

Commodity Class	Code[a]	Commodity
1	0103	Corn
2	0107	Wheat
3	0111	Soybeans
4	2049	Grain mill products[b]
5	0102	Barley and rye
	0104	Oats
	0105	Rice, rough
	0106	Sorghum grains
	0119	Oilseeds[b]
6	0911	Fresh fish, except shellfish
	0913	Menhaden
	0912	Shellfish, except fresh
7	0931	Marine shell
8	1011	Iron ore and concentrates
	1021	Copper ore and concentrates
	1051	Bauxite and other aluminum ores and concentrates
	1061	Manganese ores and concentrates
	1091	Nonferrous metal ores and concentrates[b]
9	1121	Bituminous coal
10	1311	Crude oil
11	1442	Sand and gravel
12	1471	Phosphate rock
	1479	Natural fertilizer materials[b]
13	1491	Salt
	1499	Nonmetallic minerals, except fuel[b]
14	1493	Liquid sulfur
15	2014	Tallow, animal fats, and oils
	2042	Prepared animal feeds
	2061	Sugar
	2062	Molasses, inedible
	2091	Vegetable oils
	2092	Animal oils
16	2810	Sodium hydroxide
17	2811	Crude products from coal tar, petroleum and natural gas
	2920	Petroleum coke
18	2813	Alcohols
	2817	Benzene and toluene
19	2818	Sulfuric acid
20	2819	Basic chemicals and products[b]
21	2871	Nitrogenous fertilizer and fertilizer materials, manufactured
	2879	Fertilizers and fertilizer materials[b]
22	2872	Potassic fertilizer materials
	2873	Superphosphate
23	2911	Gasoline
	2912	Jet fuel
	2913	Kerosene
24	2914	Residual fuel oil
25	2915	Distillate fuel oil
26	2916	Lubricating oil and greases
27	2917	Naptha and other petroleum solvents
28	2918	Asphalt, tar and pitches
29	2921	Liquid petroleum gases, coal gases, natural gas, natural gas liquids
30	2991	Petroleum and coal products[b]
31	3311	Pig iron
	3312	Slag
	3313	Coke, pitches, etc.
	3318	Ferroalloys
	3319	Primary iron and steel products[b]
	3321	Nonferrous metals, primary smelter products
	3323	Lead, zinc and alloys, unworked
	3324	Aluminum and alloys, unworked
	3322	Copper alloys, unworked
32	3314	Iron and steel ingots, forms, etc.
	3315	Iron and steel bars, rods, etc.
	3316	Iron and steel plates and sheets
	3317	Iron and steel pipe and tube
33	4011	Iron and steel scrap
	4012	Nonferrous metal scrap
	4022	Textile waste scrap and sweepings
	4024	Paper waste and scrap
	4029	Waste and scrap[b]
34	0101	Cotton, raw
35	1411	Limestone flux and calcareous stone
36	4118	Waterway improvement material
37	3241	Building cement

[a] Waterborne Commerce Statistics Center. [b] Not elsewhere classified.

Table 2. Regression of miles on line-haul rate (1977) by commodity class.

Commodity Class	No. of Observations	R^2	Standard Error	Intercept	Slope per 100 Miles
1	33	0.72	0.85	1.844	0.306
2	21	0.75	1.20	1.339	0.388
3	30	0.78	1.00	1.664	0.301
4	21	0.43	1.34	2.222	0.253
5	11	0.74	1.45	-0.14	0.663
6	-	-	-	-	-
7	4	-	-	-	-
8	51	0.43	1.85	1.770	0.273
9	69	0.61	1.14	1.426	0.274
10	15	0.55	1.31	2.028	0.280
11	15	0.70	0.47	1.305	0.249
12	6	-	-	-	-
13	34	0.27	2.79	2.802	0.244
14	-	-	-	-	-
15	27	0.47	1.52	3.226	0.327
16	7	-	-	-	-
17	49	0.48	2.66	2.231	0.350
18	60	0.66	2.49	1.970	0.511
19	8	-	-	-	-
20	38	0.30	3.34	2.870	0.365
21	105	0.36	1.84	2.842	0.257
22	25	0.25	1.31	2.470	0.173
23	38	0.56	1.47	1.136	0.287
24	34	0.53	1.73	1.182	0.342
25	59	0.83	1.25	0.417	0.447
26	57	0.77	1.42	0.338	0.486
27	22	0.61	2.35	2.657	0.453
28	21	0.50	2.09	3.022	0.399
29	8	-	-	-	-
30	9	-	-	-	-
31	61	0.49	2.43	2.217	0.386
32	82	0.53	2.88	3.182	0.589
33	44	0.19	1.92	4.689	0.233
34	20	0.29	4.63	3.923	0.522
35	31	0.57	2.22	0.045	0.684
36	2	-	-	-	-
37	8	-	-	-	-

Note: Does not include shipments with fuel surcharge or minimum tonnage rate.

plete the data collection due to the geographic dispersion of the companies and the fact that many had to be visited twice for the data collection because they had not fully understood how to respond to the information request. Although almost all of the companies cooperated, in some cases data were unavailable or partly or wholly unusable, which reduced the actual number of rates gathered.

DATA BASE (1977)

The general type of sampling plan is a stratified one-stage design. For the selection, the sampling unit is defined as a commodity movement of a given commodity group by a given towboat operator between a given set of origin-destination (O-D) docks in a given season of the year. These units are then stratified by (a) season of the year (4), (b) commodity group (36), and (c) O-D area (14x14). From each stratum of this three-way stratification, one unit is selected, the probability of selection being proportionate to the tonnage for that unit (as related to total stratum tonnage). All of the commodity movements thus selected constitute the sample for waterway rates.

CONSIDERATIONS IN SAMPLE DESIGN

As in all sample designs, one consideration was the limitations on the sample size imposed by costs. A total of 1700 samples were selected out of a desirable sample size of 4100.

The second major consideration was the manner in which estimates would be made from sample data. Since parametric estimates were contemplated, it was considered essential that commodity movements be stratified by origin and destination so that the whole range of variables highly correlated with rates would be represented. Thus, one obtains the full range of such variables as mileage, river direction, and number of locks traversed for each commodity. Representing the extreme ends of the range in the sample will contribute to more precise sample estimates, since regression estimates are more precise for interpolated values than for extrapolated values.

The third major consideration in the design involved the considerable variation expected in tonnage among individual shipments as well as from dock to dock. Because of the large number of strata involved in the season/commodity/O-D stratification, it was not possible within the sample-size limitation to provide for a size stratification. Making the selection so that probability of selection is proportionate to tonnage approximates a size stratification.

SIMPLE REGRESSIONS

As a first step in the regression analysis, the regression of river miles on line-haul rate has been calculated for each commodity group. No regression statistics are given for any class for which there are less than 10 degrees of freedom (12 observations). The commodity classes are given in Table 1, and the regression values are given in Table 2.

The values of R^2 (the percentage of variation in line-haul rate that is explained by the relation with miles) are rather modest for most commodity groups. Indeed, they are very low for commodity groups such as 20, 23, 24, and 34. However, it is hoped that there will be substantial improvement as more variables are added in further analysis. The desirability of splitting up these commodity classes should also be investigated. There were 10 commodity classes for which the sample was too small for the computation (it is hoped that these can be included when the whole sample becomes available); e.g., $Y = 1.844 + 0.306$ (distance/100) for corn. It should be noted that the slope of the regression line is given for miles expressed in units of 100 miles.

The regression values reported were calculated from the full data base without any deletions for "outlier" observations. Examination of the residual plot for each of the regressions indicates a number of such "outliers", but they will not be considered for deletion until a much later stage in the analysis.

SUMMARY

With the cooperation of the waterway carrier industry, it was possible to develop baseline characteristics of line-haul rates. This study is most unique in that all the rates were verified. Major commodity groups exhibit reasonable regression characteristics. Other commodity groups, due to the small sample size, exhibit a low level of regression. The results of this study will be a critical input to investment analysis as well as future rate analysis (e.g., 1980).

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Mathematical Model of Inland Waterway Port Operations

MICHAEL S. BRONZINI AND ROBERT E. STAMMER, JR.

An inland waterway port model suitable for port planning and operations studies is developed. The model design is based on a critical review of the literature and of available data sources and on field observations of port operations at typical inland waterway terminals. The model breaks port operations down into seven elementary processes. Submodels of each process are developed by using queuing theory, probability, and other appropriate tools.

Inland waterway planners must respond to a variety of challenges--economic, environmental, operational, and managerial. Many analytic methods are available to assist planners in meeting these challenges. However, these methods are notably deficient when applied to inland waterway ports.

The major objective of this research was to develop a quantitative mathematical model to study the operating characteristics of inland waterway port facilities. In particular, the model is to be used to estimate port capacity and the cost and time associated with port operations at various levels of cargo throughput. These estimates are useful for freight system policy and planning studies. The model will also determine the impacts of operational changes on port capacity and delay.

Although models have existed for some time for tow movements through inland waterway channels and locks and for operations at ocean ports, there is currently very little understanding of inland waterway port operations among waterway planners and analysts. The research described in this paper should encourage the incorporation of inland port considerations into the inland waterway planning process. The first phase of this research was limited to model development and definition, but a succeeding computer programming and model testing phase is nearing completion.

PREVIOUS RESEARCH

A comprehensive literature review revealed a scarcity of inland waterway port models. Most past research studies have concentrated on the analysis and modeling of seaports. Abstracts of 26 selected literature sources are presented in the final report (1). Recent research, such as the Inland Navigation Systems Analysis study (2) and the Mid-America Ports Study (3), was especially helpful. Ongoing activities such as the National Waterways Study and current U.S. Department of Transportation efforts in the area of energy transportation were also reviewed. This literature search verified that the model to be developed would fill a definite gap in current analytic methodology.

Probably the most valuable data source reviewed in this study is the extensive inland terminal facility inventory completed by the U.S. Maritime Administration as part of the Mid-America Ports Study. This port data base covers 1200 terminals on the Mississippi River and its tributaries and includes both physical and operational data, such as

1. Location,
2. Fleeting area characteristics,
3. Pier dimensions and construction characteristics,
4. Type of cargo handled,
5. Availability of truck and rail access,
6. Cargo storage areas, and
7. Types and characteristics of handling equipment.

These data, which include port throughput capacities, can be used as model input data for validation testing.

INLAND PORT OPERATIONS

The following inland river ports and terminals were visited during this research:

Port	Terminal
Port of Metropolitan St. Louis	St. Louis Terminals Corporation
	Tri-City Regional Port (Granite City, Illinois)
	Bulk Services Corporation
	Apex Oil Company
	Art's Fleeting Service
	Granite City Terminals Corporation
	St. Louis Grain
	Peabody Coal Company
	American Commercial Terminal
Wood River, Illinois	American Oil Company
Memphis, Tennessee	Memphis-Shelby County Port Authority
	Ten-Tex Marine, Inc.
	Mid-South Terminals Corporation
	Island Terminal Company
Pine Bluff, Arkansas	Pine Bluff-Jefferson County Port Commission
	Arkansas River Terminal (Port of Pine Bluff)
	Cargo Carriers, Inc.
	Martin Terminals Company
Little Rock, Arkansas	Inland Rivers Terminal Company
Cincinnati, Ohio	Valley Terminal Company
	Tresler Oil Company
	River Transportation Company
	Columbia Marine Services
Louisville, Kentucky	Riverway Louisville Terminal Company
	Missouri Portland Cement Company
	River Road Terminals, Inc.
	American Commercial Terminal
	Chemtec Industries, Inc.

The visits to the Port of Metropolitan St. Louis and Cincinnati included a boat tour of the port facilities.

The major purpose of these visits was to observe layout, equipment, and operating practices of a variety of ports. Emphasis was placed on characterizing the range of normal operations, observing typical practices, and obtaining photographs and plan drawings of port facilities. Labor practices, market penetration, port economics, and the interactions between port operators, fleeting and harbor services, and towing companies were also discussed.

Throughout the field observations, cooperation by the terminal operators was excellent. The operators' candid discussions of their operating experiences represent their best estimates of what constitutes "typical" conditions.

Some typical materials-handling rates at inland marine terminals for various commodities and typical crew sizes are given below (none of the terminals visited reported unloading activity for coal):

Commodity	Handling Rate (tons/h) Loading	Handling Rate (tons/h) Unloading	No. in Crew
Dry bulk	200-450	100-325	3-5
Coal	700-1400	--	5-6
Liquid bulk	275-400	250-325	2
Iron and steel	100-150	50-150	5-7
General cargo	100-200	40-175	5-7

These represent effective transfer rates rather than the instantaneous capabilities of the crews and equipment. These rates are noticeably lower than those typical of tidewater and Great Lakes ports, primarily because of lower mechanization and smaller crew size. Loading is faster than unloading due to the gravity assist.

MODEL CONCEPT

Figure 1 shows the basic elements of an inland waterway port. The port model is defined to include all cargo transfer facilities lying between designated river miles (A, B, C, and D in Figure 1). Some ports may contain only one terminal whereas more complex ports will be composed of multiple terminals. Each terminal serves one type of commodity and is usually either a loading or unloading terminal, although some terminals, such as those that handle general cargo, both load and unload barges. A terminal, then, may have one or more docks, aprons, storage areas, and waterside and landside cargo transfer facilities. Thus, the port the modeler desires to study can be represented by the number and types of terminals, their associated docks, and any fleeting areas that lie between designated river miles. The flexibility of designating specific river-mile boundaries will allow the model to be compatible with existing data collection and analysis systems.

The model is intended to apply to river ports only. Where an inland waterway port interfaces with Great Lakes or ocean shipping, the other waterborne mode will be treated similarly to a land mode. Although the model emphasizes tows rather than self-propelled vessels, it has sufficient flexibility to accommodate self-propelled vessels when necessary.

Figure 2 shows the general traffic patterns within an inland waterway port complex. The diagram indicates that tows stopping at the port will travel either to a fleeting area or directly to the appropriate terminal whereas other tows may pass directly through without interfacing with any port activity.

Figure 3 defines the terminal elements. Cargo is interchanged at the terminal either with a waterside plant or with another transportation mode. The transfer between the other mode and the inland waterway may occur directly or may be buffered through the terminal storage areas. The port activities are defined to include the transfer of cargo to or from the user's storage facilities and to or from the interfacing cargo vehicle (railcar, truck, ocean barge, etc.). Subsequent material movements within the plant and dispatching of loaded or unloaded cargo vehicles are not included because it is assumed that these activities can occur without interfering with terminal operations. On the other hand, delays that occur while equipment is being marshalled to facilitate the transfer of cargo across the system boundary will be considered within the model. Most terminals serve either a waterside user (who usually owns the terminal) or other transportation modes, but not both.

MODEL STRUCTURE AND LOGIC

As mentioned earlier, the port is defined as a set of geographically contiguous terminals. Each terminal may have several docks operating in parallel, where docks are unique to commodity groups (i.e., all handle liquid bulk, dry bulk, or general cargo). Each dock may also have several berths that operate in parallel.

This model structure permits each terminal to be modeled in considerable detail, or all terminals of a particular type can be aggregated and treated as a single terminal, depending on the desires of the analyst. When individual terminals are grouped into a single terminal (e.g., a liquids terminal), the single terminals can be modeled by considering them

Figure 1. Inland waterway port.

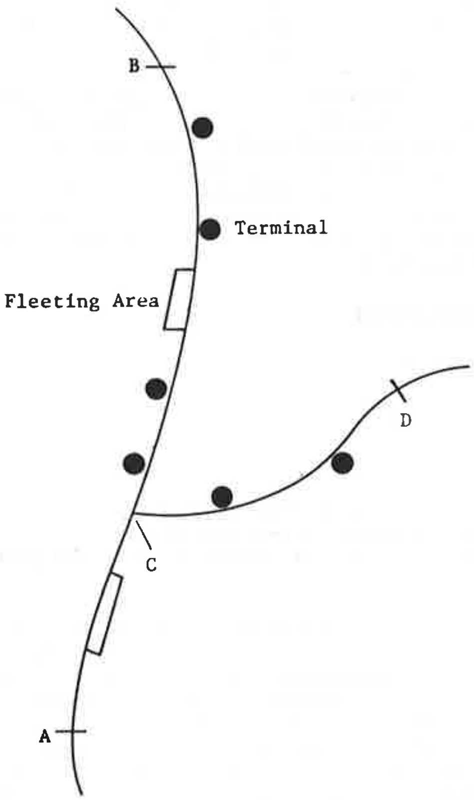
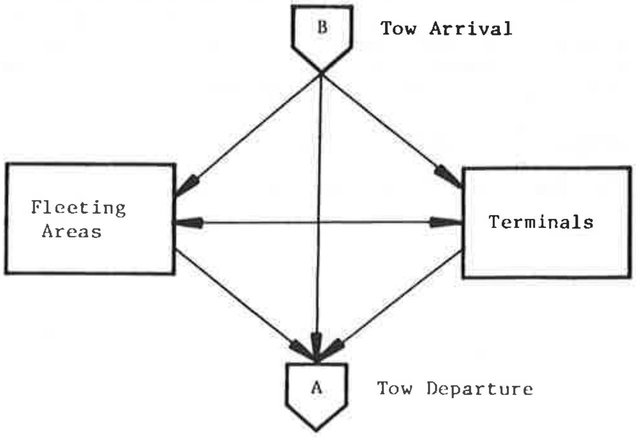


Figure 2. General port traffic flow.



to be individual docks (e.g., chemical docks, petroleum docks, etc.), each of which may have several berths.

Based on previous research and on the field observation of port operations, a port model consisting of a series of seven submodels was developed. Each submodel represents one type of activity, requires a significant amount of time to complete, and represents one segment of the total port operation.

The seven activities for which submodels were developed include

1. Tow travel,
2. Harbor tow travel,
3. Barge pickup and delivery,
4. Fleet dispatching,
5. Barge loading and unloading,
6. Dock access, and
7. Tow dispatching.

Mathematical relations for each of these seven submodels were developed and range in complexity from simple equations to more complex algorithms and queuing theory equations.

The following sections detail the mathematical relations used to represent the seven activities. In each case, the submodel produces an estimate of the average time required to complete the activity. Figures 4 and 5 show the sequence of inbound and outbound activities, respectively, and the numbers in the boxes correspond to the activity numbers and submodels defined below.

Activity 1: Tow Travel

The process for tow travel is

$$t_{1d} = X_d/v_t \tag{1}$$

where

t_{1d} = travel time to or from terminal d,
X_d = travel distance to terminal d, and
v_t = average tow travel speed within the port area.

Tow travel speed is actually a function of many variables, including towboat horsepower; tow draft, length, and width; and channel depth and width. In addition, tow speed depends on travel direction (upstream or downstream) and current velocity. However, at the scale of analysis of the port model, tow travel times are on the order of 1 h or less whereas several other port processes require many hours or even days. Hence, there is no need to incorporate a sophisticated model of tow speed. Average travel speed provides sufficient accuracy.

Several mathematical models of tow speed are available (2,4). The analyst may wish to use these models to estimate average tow speeds. Such results should be tempered by any speed restrictions that may apply to the harbor area being modeled.

Activity 2: Harbor Tow Travel

The process for harbor tow travel is

$$t_{2d} = X_d/v_h \tag{2}$$

where

t_{2d} = travel time of harbor tows to terminal d and
v_h = average harbor tow travel speed.

Harbor tows are normally small tows that consist of one to four barges pushed by a harbor boat of

Figure 3. Elements of a terminal facility.

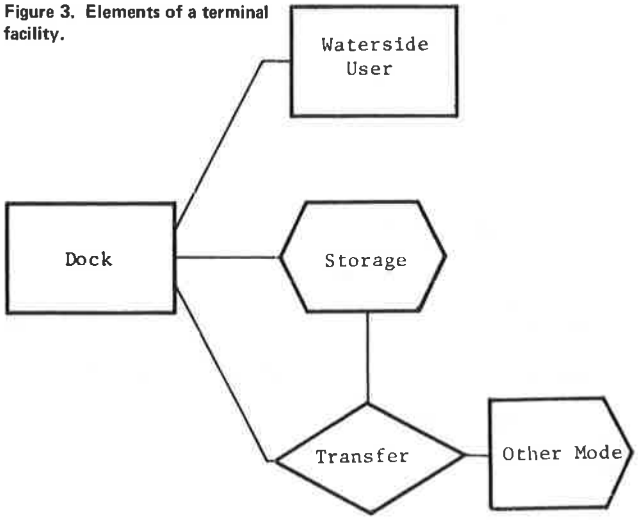


Figure 4. Inbound activities.

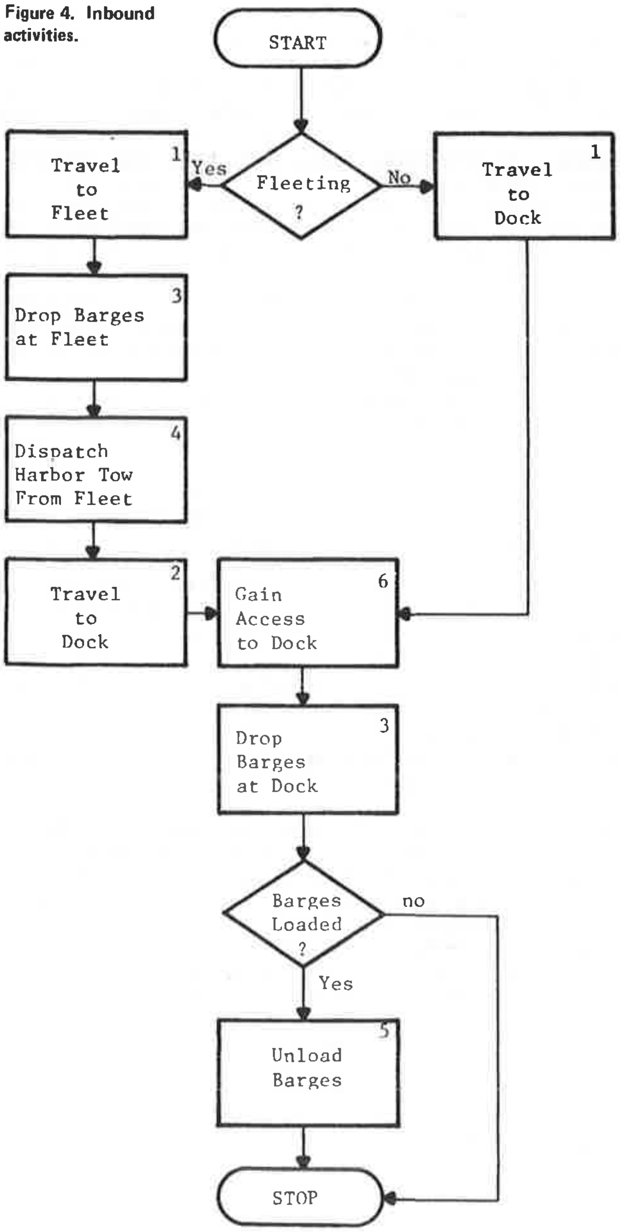
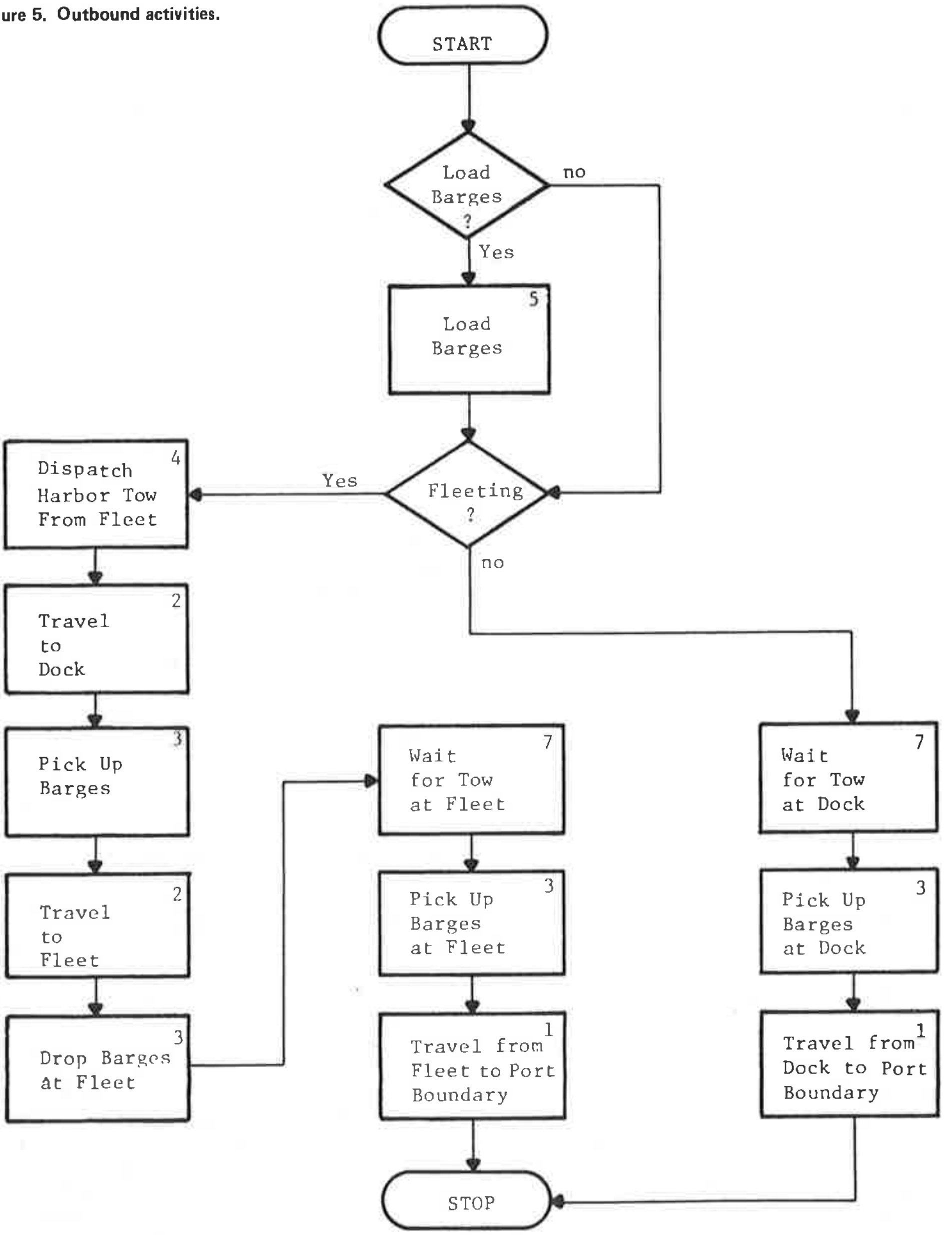


Figure 5. Outbound activities.



500-1500 hp. They may have travel speeds substantially different from those of line-haul tows and so are treated separately in the port model. However, the analyst may safely use $v_h = v_t$ for typical fleeting activities without introducing significant error.

Activity 3: Barge Pickup and Drop-Off

The process for barge pickup and drop-off is

$$t_{3i} = \sum_n p_{ni}\,[a_1 + a_2\,(n - 1)] \qquad i = d, f \qquad (3)$$

where

t_{3d} = average time required for a line-haul or harbor tow to pick up or drop off barges at terminal d,
t_{3f} = average time required for a line-haul or harbor tow to pick up or drop off barges at fleeting area f,
p_{nd} = probability that n barges are picked up or dropped off at one time ($\sum_n p_{nd} = 1.0$),
a_1 = time to pick up or drop off the first barge handled, and
a_2 = time to pick up or drop off each additional barge.

Barges are picked up and dropped off at both fleeting areas and terminals, by both line-haul tows and fleeting-service tows. This time element includes only the actual barge handling time, exclusive of any dispatching or congestion delays. Port operators indicate that this operation requires 10-20 min/barge, 15 min being a representative average. There is some time savings when more than one barge is handled during one stop, so the incremental time (a_2) is on the order of 10 min. These typical values seem to hold across all types of terminals handling a variety of products.

Activity 4: Fleet Dispatching

The process for fleet dispatching is

$$t_{4dg} = 1/(A \cdot B_{g-1} \cdot B_g) \qquad g = 1, 2, \ldots G \qquad (4)$$

where

t_{4dq} = average time elapsed between a request for fleeting service and the departure of a harbor tow for terminal d in priority group q,

$A = h![(h/t_f - y_f)/r^h] \sum_{j=0}^{h=1} (r^j/j!) + (h/t_f)$,

$B_g = 1 - \left(\sum_{i=1}^{g} y_{fi}\right)/(h/t_f)$,

$B_0 = 1$,

G = number of terminal priority groups ($G \geq 1$),

h = number of harbor boats in service at any one time ($h \geq 1$),

t_f = average harbor tow service time $= [\sum_d (Q_{fd}/b_{hd})(t_{3d} + 2t_{2d})/\sum_d (Q_{fd}/b_{hd})] + t_{3f}$,

y_{fq} = average rate of requests for service by terminal priority group q = $(2Q_q/b_{hq})/T_f$,

r = average harbor boat use = $t_f y_f < h$, $y_f = \sum_q y_{fq}$,

Q_{fd} = total barges fleeting for terminal d,

Q_q = total barges fleeted for priority group q = $\sum_{d \varepsilon g} Q_{fd}$,

T_f = total time fleeting service is in operation,

b_{hd} = average number of barges per harbor tow trip to terminal d = $\sum_n np_{nd}$, and

b_{hq} = average number of barges per harbor tow trip to a terminal in priority group q = $\sum_{d \varepsilon g} Q_{fd}b_{hd}/Q_q$.

The fleeting service is modeled as a nonpreemptive priority queuing system (5). There are G priority groups (group 1 has the highest priority and group G the lowest), and the requests for service from the highest-priority group in the queue are answered on a first-come, first-served basis. Assignment of priority groups is entirely left to the discretion of the model user. One assignment rule that seems to correspond to actual practice in many cases is to rank the terminals on fleeting service use and to form groups so that $Q_1 > Q_2 > \ldots > Q_G$.

In this queuing model, the system has h service channels, where h is the number of harbor boats operated by the fleeter. Each harbor boat is assumed to have the same average service time (t_f), which is the average time (weighted by number of trips) needed to pick up or drop off barges at the fleeting area, to travel to and from the terminal, and to drop off or pick up barges at the terminal. Furthermore, the service time is assumed to be an exponentially distributed random variable. Although the assumption of equal service time is not generally true, in most cases the service-time differentials are not very large. The distribution assumption is also questionable, but not critical.

The rate of service requests is different for each priority group and is calculated as twice the number of barges fleeted divided by the average tow size and distributed over the total operating time. A Poisson input process is assumed.

Activity 5: Load and Unload Barges

The processes for loading and unloading barges are

$$T_{5dki} = q_k/u_{dki} \qquad i = 1, u \tag{5}$$

$$t_{5dki} = T_{5dki} + (T_{5dki}/H_{dk})_I(24 - H_{dk}) + P_w(168 - 24D_{dk}) \qquad i = 1, u \tag{6}$$

where

t_{5dkl} = time to load one barge with commodity k at terminal d,

t_{5dku} = time to unload one barge of commodity k at terminal d,

q_k = average barge load for commodity k,

u_{dkl} = average effective barge loading rate for commodity k at terminal d,

u_{dku} = average effective barge unloading rate for commodity k at terminal d,

H_{dk} = average hours per day that berths serving commodity k are in service at terminal d,

$(x)_I$ = largest integer contained in x,

$P_w = \{1 - \exp[-L(168 - 24D_{dk})]\}[(7 - D_{dk})/7]$,

D_{dk} = average days per week that berths serving commodity k are in service at terminal d,

$L = (\sum_d \sum_i N_{dki})/(W_{dk}D_{dk}H_{dk})$,

N_{dkl} = total number of barges of commodity k loaded at terminal d,

N_{dku} = total number of barges of commodity k unloaded at terminal d, and

W_{dk} = weeks during the analysis period that berths serving commodity k are in service at terminal d.

In Equation 6, the first term is the number of hours required for the commodity transfer process. The second term captures delays incurred during daily nonoperating periods, if any, for barges that require more than one day to load or unload. The last term accounts for weekend periods of inactivity. In this term, P_w is the probability that a barge would complete service during the weekend hours. The expression for P_w assumes that barge arrivals for service during operational hours follow a Poisson process and barge service times are exponentially distributed. This implies that the completion process is also Poisson. The exponential factor is simply the probability that one or more barges will finish the loading or unloading processing during any period of ($168 - 24D_{dk}$) consecutive hours, and the remaining factor is the probability that this period falls on a weekend. The distribution assumptions made here are required by the submodel for activity 6; hence, they are used here primarily to maintain consistency rather than for any compelling theoretical or empirical reasons. The loading and unloading rates used here should be the controlling rate for the berths servicing commodity k, including the effects of the system used to move materials between the apron and the storage or intermodal transfer facilities of the terminal.

Equation 6 produces estimates of the total time required to process one barge completely. The average transfer time for the cargo involved will be approximately half the barge holding time. It is possible to compute the exact cargo delay time, but the approximation is sufficiently accurate.

This submodel can also be used to compute the towboat delay for unit tows. In this case, the towboat and barges will be held for as long as it takes to complete a number of consecutive loading or unloading operations. To account for this, Equation 5 is modified as follows:

$$T'_{5dki} = (n_{dkt}/n_{dk})\,T_{5dki}$$

where n_{dkt} is the number of barges in a unit tow of commodity k at terminal d and n_{dk} is the number of (simultaneously operating) berths serving commodity k at terminal d.

Activity 6: Access Dock

The process for access-dock activity is

$$X_{6dk} = \left\{ [(Y_{dk}/M_{dk})^{n_{dk}} R_{dk}] / [Y_{dk} n_{dk}! \, (1 - R_{dk})^2] \right\} C_0 \qquad (7)$$

where

t_{6dk} = average time between arrival of a barge of commodity k destined for terminal d and the time that the terminal is readv to receive the barge,
Y_{dk} = average rate of arrival of barges of commodity k at terminal d = $(n_{dk1} + N_{dku})/(W_{dk}D_{dk}H_{dk})$,
M_{dk} = average barge service rate per berth serving commodity k at terminal d = $1/[2t_{3d} + (N_{dk1}T_{5dk1} + N_{dku}T_{5dku})/(N_{dk1} + N_{dku})]$,
n_{dk} = number of berths available to serve commodity k at terminal d,
R_{dk} = average use of berths serving commodity k at terminal d = $Y_{dk}/(n_{dk}M_{dk}) < 1$, and

$$C_0 = 1/\left\{ \sum_{j=0}^{n_{dk}-1} [(Y_{dk}/M_{dk})^j/j!] + [(Y_{dk}/M_{dk})^{n_{dk}}/n_{dk}! \, (1 - R_{dk})] \right\}$$

Then

$$t_{6dk} = X_{6dk} + \left\{1 - \exp[-Y'_{dk}(24 - H_{dk})]\right\} [(24 - H_{dk})^2/48] + \left\{1 - \exp[-Y'_{dk}(168 - 24D_{dk})]\right\} [(168 - 24D_{dk})^2/336] \qquad (8)$$

where $Y'_{dk} = Y_{dk}D_{dk}H_{dk}/168$.

The terminal is modeled as a queuing system with identical parallel servers, where each berth servicing a commodity is one server. Service time is exponentially distributed with mean $1/M_{dk}$ and includes the average time the berth is occupied by a barge (drop off, load-unload, pick up). Arrivals at the dock are Poisson at mean rate Y_{dk}. Equation 7 is the expression for average waiting time due to berth occupancy. Equation 8 adds to this waiting time in port due to arrivals during nonoperating periods (nights and weekends). Again, Poisson arrivals and exponential service are assumed. In this case, however, the arrival rate is adjusted to reflect arrivals occurring during 168 h/week. The general form of both the second and third terms of Equation 8 is delay = probability of arrival during T hours x probability that T is a nonoperating period x average delay during period T.

Submodel 6 assumes that each barge is a separate traffic unit. This is incorrect for unit tows. The correct result can be obtained by considering such tows to be single "barges", with capacity equal to the tow capacity. This adjustment does not affect delays due to berth use (Equation 7) but causes a reduction in the probability of arrival during nonoperational periods. A commensurate adjustment to the number of berths must also be made. In most cases, unit tows serve exclusive terminals, so there is little problem with applying the model in this fashion. As a first approximation, it is acceptable to ignore the unit tow problem, with the recognition that delay will be somewhat overestimated. A more detailed model would consider unit tows as bulk arrivals at an n-server queuing system.

Activity 7: Tow Dispatching

The process for tow dispatching is

$$t_{7k} = T/N_k \qquad (9)$$

where

t_{7k} = average time that barges with commodity k wait for a tow at a dock or fleeting area,
T = total time in the analysis period, and
N_k = number of tows serving commodity k that call at the port during time T.

Equation 9 depends on the assumptions that barges become ready for pickup randomly following a Poisson process and tow arrivals are also Poisson. Hence, the time from a barge arrival to a tow arrival is a random variable exponentially distributed with parameter N_k/T. If unit tows are involved, Equation 9 does not apply, since the towboat waits for its barges. In this case, $t_{7k} = 0$.

RESEARCH IN PROGRESS

Example calculations made with the model are presented in the project final report (1). Based on those examples, the model appears to give reasonable results. More thorough examples and computations are being performed now that the model is programmed for the computer, since manual calculations can become quite tedious. The final report of the second research phase will include program documentation and the results of model testing.

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Selected Productivity Comparisons in Surface Freight Transportation: Inland Water, Rail, and Truck, 1955-1979

SAMUEL EWER EASTMAN

Aggregate productivity measurements for surface freight transportation are made, limited to a single measure of output—net ton-miles of transportation produced—for measured inputs of labor, capital, and energy. The ton-mile output measure was selected because it is shown that inland barge carriers and railroads, the principal comparison made, carry cargoes that average out to nearly the same density, 60-65 lb/ft^3. In addition, equipment use by rail and barge is compared. Barges are shown to be more productive than railroads by all measures studied. The analysis shows that labor productivity for water, measured in ton-miles per employee year, is four to five times greater than for rail for selected periods beginning in 1955. An average annual aggregate labor productivity growth rate of about 10 percent is shown for both water and rail. In contrast, truck productivity shows little gain over the period. Inland water capital productivity, measured in ton-miles per dollar of investment, is two to three times that of rail. Comparisons of water and truck show that investments in water transportation have been four to seven times more productive in recent years. On a route-mile basis, barging ranges from more than twice as energy efficient to nearly four times as energy efficient as rail. When circuity is taken into account—for example, for shipments between Minneapolis and New Orleans—barges continue to outperform railroads in energy productivity, the extent depending on which of the many available rail routes is used. In comparisons of barge use and rail freight-car use, rail freight-car use is found to be substantially lower and to have declined in recent years.

The operation of a transportation organization can be viewed as a blending of various scarce resources into an efficient and effective combination to provide a service to the user public. The chief scarce resources used in this type of service are labor, capital, and energy. These particular classes of resources can also be viewed as major expense items that go into the provision of transportation services for the general population.

When one views the use of scarce resources, the concept of productivity becomes a useful focus because it provides a definition of efficiency for comparative purposes. Thus, one can compare the productivity of competing services; the most productive service--i.e., that which uses less resources to produce the same service--may be regarded as the more efficient.

Productivity is traditionally defined as the ratio of output to input. In order to properly capture the total perspective of a firm's operation, the total output of the firm should be related to the combination of the partial inputs--i.e., labor, capital, and energy. The traditional view of productivity, largely effected by the Bureau of Labor Statistics, is the ratio of output to labor hours (1). The more modern view attempts to relate the entire spectrum of scarce resources as they are marshaled to produce the required level of service (2-5). This type of total factor productivity analysis is difficult to do at the aggregate industry level in the transportation field due to lack of data. However, at the individual transportation organization level, the total factor productivity perspective shows great promise of providing an understanding of the use of the various scarce economic resources as they are combined to produce a service to the public. A recent study conducted in the environment of a single motor-carrier firm showed the feasibility of this type of analysis (6).

This paper addresses the relative trends in productivity of the waterway mode of transportation as it compares with the two main competitive modes, truck and rail. All three of the major dimensions--labor, capital, and energy--are considered. Capital productivity is considered both on an aggregate basis and in terms of equipment use.

It is important to exercise considerable care in the manner in which outputs and inputs are defined prior to the combination within the productivity relation. If dollars of revenue are used as an indicator of the output of a transportation organization, the impact of inflation will readily confuse and distort the analysis. To use the productivity concept properly, the output should be in quantities and the input should also be in a relevant quantity unit.

The output of a transportation organization is a service. This service contains several key dimensions:

1. Efficiency in the movement of freight,
2. Timely delivery to the destination, and
3. Quality of service in terms of frequency, reliability, lack of damage, and supply of information en route.

This analysis concentrates on the efficiency dimensions. The first basic question to be addressed is the nature of the physical unit that will be used to represent the output of the transportation service. Obviously, a transportation organization is in the business of moving freight from origin to destination in a timely manner with minimal damage. One could address as a unit of output several different quantity units:

1. Number of customers served,
2. Number of individual bills of lading transported,
3. Number of tons moved through the system,
4. Number of ton-miles transported through the system, and
5. Value of goods transported.

The unit chosen must be the one that has the most meaning and can be derived from normal information systems within the organizations and within the industries. The first two units of output listed above could be extremely misleading as one tried to perform trend analysis to ascertain whether an industry was becoming more or less productive. Tons of freight moved can also be misleading, especially if the average length of a shipment changes over time, which appears to be the case in the transportation industries. For example, in the period from 1950 to 1975, the average length of haul for a Class 1 motor common carrier increased from 235 to 286 miles. In the rail system, an increase from 416 to 518 miles was exhibited. For water transportation on rivers and canals, in 1955 the average length of a shipment was 256 miles and in 1975 it had increased to 358 miles (7).

The ton-mile appears to be the most relevant indicator of output for a transportation organization, but even this concept can be misleading (8-14). If the average density of freight moves from the heavier level to a lighter level, the productivity of the freight movement could be affected solely because of the nature of the freight density. The space occupied on the transportation equipment and the labor necessary to move the freight might remain stationary while the ton-mile figure decreased. This would indeed show a decrease in productivity, which might not be substantial when one looked deeper. One other useful aspect of the ton-mile concept is that it indicates the ability of the transportation organization to properly use and schedule its fleet. If traffic can only be maintained in a one-way mode, a great deal of deadhead traveling back to origin will be needed, which would use all of the input resources while providing no ton-miles of service. Thus, the effectiveness with which the transportation network is managed will be partly captured with the ton-mile concept.

AGGREGATE PRODUCTIVITY COMPARISONS: LABOR AND CAPITAL

Labor and capital productivity estimates that use ton-miles as the measure of output are given in Tables 1 and 2 at the aggregate level for water, rail, and truck and at the individual organizational level for water and truck. These productivity estimates are given for several time periods beginning in 1955. Measured in thousands of ton-miles per employee year, water labor productivity shows a relatively stable relation 4-5 times more productive than rail over the time period. In contrast, water labor productivity triples in comparison with truck productivity over the period: Water is about 10 times more productive in 1955 and about 40 times more productive in the late 1970s. This is reflected in an average annual labor productivity growth rate of 10 percent for both water and rail over the years considered but a much smaller, even negative, average annual labor productivity growth rate for trucking.

Table 1. Aggregate labor productivity for water, rail, and truck: 1955-1979.

Year	Thousands of Ton-Miles per Employee Year			Water/Rail (%)	Water/Truck (%)
	Water[a]	Rail[b]	Truck[c]		
1955	2010	524	222	26	11
1960	2817	654	147	23	5.2
1965	5040	965	173	19	3.4
1970	9097	1230	162	13	1.8
1975	8627	1411	144	16	1.7
1976	9557	1515	155	16	1.6
1977	9718	1632	184	17	1.9
1978	8280	1622	140	19	1.7
1979	7805	1658	180	21	2.3

Note: Average annual growth is 12 percent for water, 9 percent for rail, and −0.1 percent for truck.

[a] Calculations based on tons carried and average number of employees from Interstate Commerce Commission (ICC) Transport Statistics in the United States: Part 5—Carriers by Water, Class A Carriers, for respective years. Average length of haul used was for that of all inland water carriers from U.S. Army Corps of Engineers' Waterborne Commerce of the United States: Part 5—National Summaries, Table 3, page 96, for respective years.

[b] Calculations based on ton-miles and average number of employees for Class 1 line-haul railroads (7, pp. 8 and 23).

[c] Calculations based on tons carried and average number of employees from ICC Transport Statistics in the United States: Part 2—Motor Carriers, Class 1 Common Carriers of General Freight Engaged in Intercity Service, for respective years. Average length of haul used was that for all intercity motor carriers (7, p. 15).

As noted earlier, caution must be exercised in drawing hard and fast conclusions from these comparisons because of differences in cargo densities and the different services offered by the three modes. This is particularly true of water and truck comparisons, which include, for truck but not for water, labor-intensive pickup, delivery, and consolidation services that involve the handling of low-density freight. A productivity comparison of water and truck, limited to line-haul service, is given later in this paper.

Aggregate capital productivity for the three modes measured in ton-miles per dollar of property and equipment and per dollar of total assets is given in Table 2 for the years 1955-1979. Again, the water-rail comparison is relatively stable: Water capital productivity is about twice that of rail based on property and equipment investment (rail right-of-way is included only in estimates based on total assets). Comparisons of water and truck capital productivity show investments in trucking to be about half as productive in the late 1950s but decreasing so as to be one-quarter or less productive than comparable investments in water in the late 1970s.

All of these capital productivity estimates are based on current dollars, and this during a period of substantial inflation. Since the useful life of trucking equipment (4-8 years) is substantially less than that of equipment used to produce water and rail transportation (20-30 years), the substantial decrease over the period of truck ton-miles per dollar of investment, compared with more stable values of water and rail ton-miles per dollar of investment, is partly a reflection of the inflation of the period. Truck transportation, using equipment of shorter life, shows the effect of inflation sooner. As the value of the dollar decreases, ton-miles produced per dollar invested in equipment will decline without any true change in capital productivity. By

Table 2. Aggregate capital productivity for water, rail, and truck: 1955-1979.

Year	Property and Equipment					Total Assets				
	Ton-Miles per Dollar[a]			Water/Rail (%)	Water/Truck (%)	Ton-Miles per Dollar			Water/Rail (%)	Water/Truck (%)
	Water	Rail	Truck			Water	Rail	Truck		
1955	83.0	55.1	48.6	66.4	58.5	86.3	21.2	48.4	24.5	56.1
1960	73.0	43.8	25.8	60.0	35.3	79.7	19.3	27.6	24.1	34.5
1965	80.5	48.8	23.3	60.6	28.9	81.6	23.0	23.1	28.2	28.3
1970	130.2	46.2	17.1	35.5	13.1	144.4	23.0	15.5	15.7	10.7
1975	91.1	41.8	21.1	45.9	23.2	87.5	20.1	10.3	23.0	11.8
1976	99.1	44.7	21.8	45.1	22.0	88.1	22.2	10.5	25.2	11.9
1977	85.9	43.5	21.7	50.7	25.3	76.2	21.7	10.4	28.5	13.6
1978	85.7	44.2	20.7	51.6	23.8	74.6	22.3	9.95	29.9	13.3
1979	86.4	44.0	17.6	50.9	20.4	65.9	22.0	8.78	33.4	13.3

Note: Sources of ton-mile data same as in Table 1.
All financial data taken from ICC Transport Statistics in the United States: Part 5—Carriers by Water, Part 1—Railroads, and Part 2—Motor Carriers, for respective years.

[a] Excluding reserves for depreciation.

the same token, the relatively stable showing of these values by water and rail over this period suggests that capital productivity has increased markedly in these industries.

DATA BASE AND CARGO DENSITY

Railroads have been regulated by ICC since the turn of the century; they are required to report data on traffic and finances. The series Transportation Statistics in the United States, published annually by ICC, provides one complete and continuing source of data on railroads. The foregoing analysis is based on these data. A recent study confirms the finding above that there has been a substantial growth in rail aggregate productivity (15,16).

Such a complete data base is not available for the trucking industry or for water carriers, including carriers on the inland waterways, which are the focus here. Only the regulated water carriers and trucking companies are required to report traffic and financial information to ICC--estimated to be less than 10 and 50 percent, respectively, of the industry totals (7 and Waterborne Commerce). An overall check of the data given in Tables 1 and 2, based on statistics from ICC, can be made by comparison with a hypothetical line-haul operation (common-carrier truck).

For the waterway mode, one can relate the ton-miles transported for a given one-way trip to the cost of that capital as it is deployed. For comparison purposes, it is assumed that a 30-barge tow, each barge carrying 1500 tons, is driven by a single tow boat. New capital costs of these resources are $300 000/barge and $3.5 million/tow boat. The estimated life of these resources is taken at 25 years. The capital charge should be made up of two components: a depreciation component, which allows for capital recovery, and a return component, which represents a fair return for this initial investment. For the purposes of this analysis, straight-line depreciation is used along with a 20 percent annual return requirement on the initial investment.

Thirty barges at $300 000 each = $9 000 000.
One tow boat at $3.5 million = $3.5 million.
Total new investment = $12 500 000.
Depreciation charge (25-year straight-line basis) = $500 000/year.
Return = $12 500 000 x 0.20 = $2 500 000.
Total yearly capital charge = $3 000 000/30-barge tow.

For a tow from St. Louis to New Orleans, a distance of 1039 miles, the time in transit would be approximately five days. The capital productivity, ton-miles per dollar of capital, would be 46 755 000 ton-miles/$42 857 = 1091 ton-miles/$ [$3 000 000 x (5/350) = $42 857].

In terms of labor productivity for this hypothetical trip, the ton-miles per labor hour would be

Five days x 8 crew members per shift = 960 man-hours.
46 755 000 ton-miles/960 = 48 703 ton-miles/man-hour.

For the common-carrier truck mode, for a similar trip from St. Louis to New Orleans, a distance of 673 miles, a 40-ft tractor-trailer combination would exhibit the following productivity characteristics. At a speed of approximately 45 miles/h, the trip could be completed in one full day. The weight limit of 44 000 lb for the trailer would produce a total ton-mile output of 14 806 ton-miles. The initial cost of a trailer is approximately $11 500, and the initial cost for a tractor is approximately $38 000, which gives a total vehicle capital cost of $49 500. If one uses a five-year depreciation schedule and a 20 percent return, the annual capital charge for the trailer and tractor would be $19 800. Since this trip could be completed within a 24-h period, the capital charge for this activity would be $56.57. In terms of capital productivity, 14 806 ton-miles/$56.57 = 262 ton-miles/$. Labor productivity would be 14 806 ton-miles/24 man-hours = 617 ton-miles/man-hour.

A comparison of the results for the two modes shows the following:

		Productivity	
Mode	Data	Capital (ton-miles/$)	Labor (ton-miles/ man-hour)
Waterway	Line-haul	1091	48 703
	ICC	86.4	4 460
Truck	Line-haul	262	617
	ICC	17.6	103

One would expect the line-haul productivity to be substantially higher than that reported for all operations to the ICC, and this comparison shows clearly that it is. For inland waterway, the line-haul man-hour productivity is about 10 times that of all operations (48 703 versus 4460 ton-miles). For trucking, it is about 6 times greater (617 versus 103 ton-miles). The financial comparisons give line-haul an even greater advantage, more than 12 times in the case of water (1091 versus 86.4 ton-miles) and about 15 times in the case of trucking (262 versus 17.6 ton-miles).

Finally, there is the effect of cargo density on productivity comparisons that use ton-miles. The carrier of lower-density cargoes by one mode will, in comparison, understate true productivity. The data given in Table 3 show that inland barge carriers and railroads carry cargoes that average out to nearly the same density--60-65 lb/ft^3.

ENERGY EFFICIENCY OF BARGES AND RAILROADS

A third aggregate dimension of productivity is energy. Energy efficiency, or energy intensiveness as it is often called, is measured for moving freight by ton-miles of transportation produced per gallon of fuel burned and by British thermal units (Btu) per ton-mile. The Btu measures the quantity of energy input in the productivity equation. For example, 1 gal of No.2 diesel fuel contains 138 700 Btu.

In comparing the energy intensity of barges and railroads, careful attention must be paid to making "like comparisons". In addition, water and rail transportation route circuity must be taken into account.

Comparison of the energy efficiency of a 30-barge tow of 45 000 tons, line-haul downriver on the Mississippi, with the average for all railroads hauling all cargoes favors barging. Similarly, comparison of a 110-car unit train of 11 000 tons, line-haul down the mountain to a port, with the average for all barge companies hauling all cargoes favors rail. Studies show the following comparisons of "best" and "average" cases for both barge and rail (15):

	Btu per Ton-Mile		Ton-Miles per Gallon	
Case	Barge	Rail	Barge	Rail
Best	103	396	1347	350
Average	270	686	514	202

By barge, 1 gal of diesel fuel will move 1 ton 1347 miles in the best case and 514 miles in the average case and, by rail, 1 gal will move 1 ton 350 miles

Table 3. Tons of cargo carried and cargo density for rail and inland waterway: 1978.

	Rail				Inland Waterway			
Commodity Group	Tons Carried[a] (000 000s)	Percentage of Total	Cargo Density[b] (lb/ft³)	Density Weighting[c]	Tons Carried[d] (000 000s)	Percentage of Total	Cargo Density[b] (lb/ft³)	Density Weighting[c]
Farm products	128.7	9.66	40	3.86	50.303	10.13	40	4.05
Fresh fish and other marine products	-[e]	-[e]	-[e]	-[e]	8.892	1.79	30	0.54
Metallic ores	112.5	8.45	100	8.45	6.717	1.35	100	1.35
Coal and lignite	383.1	28.76	70	20.13	114.608	23.07	70	16.15
Crude petroleum	-[e]	-[e]	-[e]	-[e]	47.426	9.55	50	4.77
Nonmetallic minerals	134.7	10.11	100	10.11	71.737	14.44	100	14.44
Food and kindred products	95.4	7.16	30	2.15	10.576	2.13	30	0.64
Lumber and wood products	95.1	7.14	20	1.43	4.878	0.98	20	0.20
Pulp, paper, and allied products	41.4	3.11	32	0.99	2.720	0.55	32	0.18
Chemicals and allied products	106.7	8.01	43	3.44	34.295	6.90	43	2.97
Petroleum and coal products	44.4	3.33	49	1.63	123.563	24.88	49	12.19
Stone, clay, glass, and concrete products	59.9	4.50	80	3.60	5.245	1.06	80	0.85
Primary metal products	60.1	4.51	155	6.99	7.869	1.58	155	2.45
Transportation equipment	32.2	2.42	6	0.15	-[e]	-[e]	-[e]	-[e]
Waste and scrap materials	37.8	2.84	100	2.84	10.853	2.18	100	2.18
Total	1332.0	100.00		65.77	496.682	100.00		62.96

[a] From Association of Railroads (17).
[b] From American Trucking Associations, Inc. (18).
[c] Column 2 x column 3.
[d] From U.S. Army Corps of Engineers, Waterborne Commerce of the United States: Part 5—National Summaries, Table 10, page 30.
[e] Quantity is negligible.

in the best case and 202 miles in the average case. On a route-mile basis, barging ranges from more than two times as energy efficient as rail (average comparison) to nearly four times as energy efficient (best comparison).

Towboats follow winding rivers, and railroad tracks are built along easy grades. The resulting water or rail route is rarely the shortest distance between origin and destination. In addition, railroads usually offer a choice of routes, and studies show that rail freight does not always move over the shortest rail route (19).

To accommodate these variables, water and rail routes are compared with the "Great Circle" distance to obtain estimates of route circuity. For example, the inland water distance from Minneapolis to New Orleans is 1.6 times longer than the Great Circle distance. The rail route can be from 1.2 to 1.9 times the Great Circle distance, depending on which railroads carry the traffic and the routes selected on those railroads. Adjustments for circuity should be applied to route-ton-mile estimates of energy intensity when comparisons are made between specific points of origin and destination (19).

A comparison has been made of the relative energy efficiency to move grain from Minneapolis to the Gulf, taking rail and water circuity into account. It shows inland water is from 45.9 to 130.7 percent more energy efficient than rail, depending on which of the 10 different rail routes studied is actually used for shipment (19).

EQUIPMENT UTILIZATION

A popular measure of productivity that is less aggregate than labor, capital, and energy is equipment utilization. It is used by management within a single firm as a tool for control of the company's operations, and it is used to compare the relative productivity or efficiency of two or more firms producing the same transportation service or product. All else being equal, the firm with higher equipment utilization may be the more efficient.

Transportation equipment utilization is generally measured in two ways. One is the frequency with which the piece of equipment--barge, rail car, or truck trailer--is in motion producing transportation (hours per day, miles per year, etc.). The other relates to whether that piece of equipment, while in motion, is carrying a load, part of a load, or moving empty into position for a load (percentage of barges in a tow that are loaded, percentage of total rail car miles that are loaded, etc.). The two measurements are often related in a given market where fewer hours on the move may mean larger individual loads when movement does take place. In addition, of course, the nature of each market itself imposes constraints--for example, where only one-way loads are possible. Such would be the case of unit coal trains operated with dedicated equipment from a single mine. Efficient equipment utilization in this case depends on train turnaround time, since the cars will all be full in one direction and empty in the other.

The data given in Table 4 show that from 1947 to 1977 annual rail car miles decreased from 32.2 billion to 28.7 billion, about a 12 percent loss over the period. However, the percentage of total car miles for which cars were loaded decreased even more sharply, from 66.4 percent in 1947 to 58.6 percent in 1977, a nearly 17 percent loss over the period. These data show, for example, that in 1977, when rail cars moved, they were loaded only 56.8 percent of the time.

Comparable historical data on barging are not available, but a 1978 U.S. Army Corps of Engineers study based on vessel logs (20) measured the percentage of barges in the tows sampled that were loaded. The results are given in Table 5 for 11 major inland river systems. Equipment utilization measured in this manner shows that traffic characteristics vary from river system to river system. Thus, on the Cumberland River, the dominant traffic movement is upriver: The study shows that 91.5 percent of the upriver barges were loaded whereas only 50 percent of the barges moving downriver were loaded. On the other hand, on both the Lower Mississippi and the Ohio, traffic is more balanced: On the Lower Mississippi, 67 percent were loaded moving downriver and 63.5 percent moving upriver; on the Ohio, 59 percent were loaded moving downriver and 65.5 percent moving upriver. Equipment utilization is shown to be the most efficient on the Black Warrior-Tombigbee River system: 72.5 percent loaded moving downriver and 78.5 percent loaded moving upriver.

An average percentage of barges loaded for all 11 river systems was estimated by weighting the values shown for each river by the percentage of total ton-miles moved on that system. As presented in Table

Table 4. Measures of freight car use for Class I railroads: 1947-1977.

Year	Car Miles (billions) Loaded	Empty	Total	Percentage of Total Car Miles That Are Loaded
1947	21.4	10.8	32.2	66.4
1951	20.6	10.6	31.2	66.0
1955	20.1	11.1	31.2	64.5
1959	17.8	10.8	28.6	62.3
1963	17.1	11.0	28.1	60.9
1967	17.4	12.2	29.6	58.9
1968	17.8	12.3	30.1	59.3
1969	18.0	12.4	30.4	59.2
1970	17.3	12.6	29.9	57.8
1971	16.5	12.7	29.2	56.6
1972	17.1	13.2	30.3	56.5
1973	18.0	13.2	31.2	57.7
1974	17.6	13.1	30.7	57.2
1975	15.1	12.5	27.6	54.7
1976[a]	15.8	12.7	28.5	55.4
1977[a]	16.3	12.4	28.7	56.8

Note: Data from Transport Statistics in the United States and prior releases, reported in Modern Railroads, July 1980, page 55.

[a] Preliminary.

Table 5. Measures of barge use: 1978.

Waterway	Direction	Barges Loaded[a] (%)	Ton-Miles[b] (000 000)	Percentage of Total	Weighting
Allegheny River	Downriver	54			
	Upriver	55			
	Total	54.5	79.5	-[c]	0
Arkansas River	Downriver	66.5			
	Upriver	50			
	Total	55.5	1 694.9	0.9	0.499
Black Warrior-Tombigbee River System	Downriver	72.5			
	Upriver	78.5			
	Total	75.5	3 971.9	2.2	1.661
Cumberland River	Downriver	50			
	Upriver	91.5			
	Total	55.5	989.4	0.5	0.277
Illinois River	Downriver	50			
	Upriver	86			
	Total	66	7 683.9	4.3	2.838
Lower Mississippi River	Downriver	67			
	Upriver	63.5			
	Total	65	105 256.6	58.9	38.285
Missouri River	Downriver	88.5			
	Upriver	64			
	Total	75.5	1 528.6	0.8	0.604
Monongahela River	Downriver	50			
	Upriver	91			
	Total	61.5	1 223.8	0.7	0.430
Ohio River	Downriver	59			
	Upriver	65.5			
	Total	62.5	38 823.9	21.7	13.563
Tennessee River	Downriver	50			
	Upriver	88.5			
	Total	59.5	4 416.6	2.5	1.487
Upper Mississippi River	Downriver	86			
	Upriver	50			
	Total	67.5	12 908.4	7.2	4.860
Total			178 577.5	99.7	64.504

[a] Calculations based on data of U.S. Army Corps of Engineers (20).
[b] From American Waterways Operators, Inc. (21).
[c] Less than 0.1 percent.

5, this calculation shows that, for all rivers in the Corp of Engineers sample, an average of 64.5 percent of the barges moving are loaded. This is a substantially higher rate of equipment utilization than the 56.8 percent shown for rail based on loaded and unloaded car mileage.

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Ferry-Service Improvements: Planning and Implementation for Long Island Sound Ferry Crossings

GERALD S. COHEN, G. FREDERICK YOUNG, DAVID I. GOODING, AND E. WILSON CAMPBELL

The Long Island Sound Ferry Service Improvement Study was initiated in March 1980 to identify possible ways to improve ferry services between Long Island and Connecticut. The events leading to legislation proposed for introduction in the New York State Legislature, which detailed a mechanism for achieving expanded cross-Sound ferry service for residents of the region, are described. The history of previous bridge and ferry crossing studies is reviewed, and the principal findings and issues of the current study are presented. The study featured technical work conducted primarily by staff of the New York State Department of Transportation and establishment of a bistate Policy Advisory Committee representing local officials, businessmen, and citizens' groups. A series of public forums was held that enabled decisionmakers to be aware of public views on the issues. Financial recommendations included the creation of a bistate commission that would oversee and assist in promoting expanded, coordinated ferry operations.

Transportation access between Long Island and New England is essentially dependent on passage through one of the world's most heavily traveled urban-core areas--the City of New York--over bridges that are already at or are rapidly approaching their capacity limits and over expressway and arterial systems that are experiencing severe congestion. The only current transportation alternatives to those routes for travel between Long Island and points throughout New England are two long-established, but also capacity-constrained, ferry services across Long Island Sound: Port Jefferson-Bridgeport and Orient Point-New London.

A number of studies of new bridges or ferry services have been undertaken since the mid-1960s, each generally reinforcing belief in the potential benefits of improved cross-Sound access but failing to establish clearly a course of action that is financially attainable and broadly supportable on both sides of the Sound. In the spring of 1980, immediately following the most recent examination and rejection of a new cross-Sound bridge at any location and for the foreseeable future, the Governors of New York and Connecticut directed their respective Departments of Transportation (DOTs) to initiate a broad, cooperative investigation of alternative improvements in cross-Sound ferry services that might offer a financially viable solution to the continuing issue of cross-Sound transportation access.

The objectives of this study have been to assess the overall desirability and feasibility of major improvements in cross-sound ferry services as transportation investments and to develop a program of near- and longer-term actions to carry out such improvements.

PREVIOUS CROSSING STUDIES

Several studies of various Long Island Sound crossings were made between 1965 and 1971, including a railroad crossing study and bridge studies by a number of groups. Many of these studies advocated a bridge between Rye and Oyster Bay. A 1965 report by the Triborough Bridge and Tunnel Authority strongly advocated a bridge from Rye to Oyster Bay.

During 1974-1975, the Tri-State Regional Planning Commission conducted a Long Island Sound Ferry Study for Connecticut and New York State. The conclusions were as follows:

1. High-speed hovercraft were too expensive.
2. Major expansion of ferry-boat services would be desirable.
3. The best crossing location, economically and operationally, would be Old Saybrook to East Marion. However, new terminals and access roads in these areas were strongly opposed by local residents and officials.
4. If such a new route were ruled out, improvements to the existing ferries would be desirable.

RECENT BRIDGE STUDY

Pressure to consider a bridge continued. In light of continued expressions of interest in, as well as opposition to, a bridge, Governor Carey directed Commissioner Hennessy (in 1979) to reexamine the feasibility of a bridge and to provide current data for decisions regarding crossings from Long Island to New England.

This study used a 22-member Policy Advisory Committee consisting of political and community leaders and concerned citizens from both New York and Connecticut. This committee met four times and formed task groups that met nine times. The committee also held six public forums at various places on both sides of the Sound. This public involvement helped to ensure a relevant, responsive study. Two major recommendations were made (1):

1. New York State should not, in the foreseeable future, devote further effort to the general or site-specific investigation of a cross-Sound bridge at any location.
2. In cooperation with local officials at current ferry terminal locations and with transportation and economic development officials from the State of Connecticut, New York should undertake the expansion of cross-Sound ferry services, which already appear to have support at the local and state levels on both sides of the Sound.

In May 1980, the Governors of New York and Connecticut appointed a Policy Advisory Committee consisting of local officials and concerned citizens to give advice and make recommendations regarding improved cross-Sound ferry services to the transportation commissioners and the study team.

GOALS OF THE FERRY STUDY

This study of Long Island-New England transportation linkages was designed to provide a set of readily implementable recommendations that had benefited fully from public exposure. The study was also designed to achieve the following objectives:

1. A reasonable degree of agreement among all significant parties on desirable and feasible services;

2. Production on an "action" program that would be supported by both state and local government and operators of current services;

3. Suggestion of both short-term improvements and longer-term service improvements over a 5- to 10-year period, a program of incremental improvements permitting promotion of improved services and assessment of realized use estimates;

4. Recognition of existing terminal locations and operations where improvements could be implemented most rapidly, as well as of continued private ownership and operation of those services in the mix of alternatives to be examined; and

5. Maximum encouragement of private funding for service improvements with minimization of public funding for cross-Sound transportation improvements or operations.

STRUCTURE OF THE STUDY

Many of the goals of the study required the achievement of a reasonable degree of agreement or consensus on appropriate actions for service improvements. It was particularly important, therefore, that the transportation commissioners, who would present recommendations to the respective Governors, be aware of all points of view and alternative solutions. The study structure was designed to ensure this knowledge.

Four major groups were involved in the study:

1. A Policy Advisory Committee--jointly chaired by the transportation commissioners and consisting of local officials, business leaders, and representatives of citizens' groups from both states--which met periodically for the purpose of providing input, suggesting avenues of technical analysis, and, most important, helping formulate recommendations for service improvements;
2. A consultant who collected needed survey data, provided background on other ferry operations, and, most important, served as a liaison and contact person for the two state DOTs and the Policy Advisory Committee and for the general public;
3. An NYSDOT technical task force that produced use and financial forecasts for alternative service and fare scenarios, analyzed study findings, and developed conclusions from the study efforts; and
4. Those citizens who provided useful input to the process through their comments at a series of public forums held in New York and Connecticut (many other comments were received in letters written to the commissioners and the local press).

Generally, the public endorsed strongly the concept of improved ferry service, but there was some opposition to extending the service to additional sites in central Suffolk County. The commissioners' recommendations (2) reflected the input of the Policy Advisory Committee, the results of the public forums, the views of the public as written in letters, and the technical reports produced by the consultant and NYSDOT staff.

STUDY FINDINGS

The following sections summarize the findings of the study team.

Present Ferry Service

Two operators currently provide ferry service across Long Island Sound. Cross-Sound Ferry Service, Inc., provides year-round service between Orient Point, New York, and New London, Connecticut. The Bridgeport and Port Jefferson Steamboat Company provides seasonal service between Port Jefferson, New York, and Bridgeport, Connecticut. These operations are labeled as lines G and C, respectively, on the map shown in Figure 1.

The Orient Point-New London service is provided by three vessels. Two of the ferries can carry 300-325 passengers and 20-22 automobiles, and the third can accommodate 300 passengers and 51 automobiles. All three vessels can accommodate trucks. Frequency of service ranges from a high of 24 one-way trips/day in the summer to a low of 6-8 trips/day during the winter. During the spring and fall months, 14 trips/day are provided. Crossing time ranges from 60 to 80 min, depending on the vessel.

Only one ferry provides the Port Jefferson-Bridgeport service. The vessel can carry 1089 passengers and 36 automobiles, but truck service is not offered. The existing vessel is more than 50 years old and on occasion has been out of service for repair. It is possible that, in the not too distant future, the owners will have to decide whether to overhaul the existing vessel or acquire another one. This service is only operated between May and October. During the summer and on weekends, 8 one-way trips are provided. Frequency of service is only 4-6 trips during the midweek period in the spring and fall. The crossing time is 90 min.

Ridership for both services has generally been increasing in recent years. In 1979, the Orient Point-New London ferry carried 257 000 passengers and 103 000 vehicles and the Port Jefferson-Bridgeport service carried 112 000 passengers and 25 000 vehicles. Although the monthly average for the Orient Point service was approximately 21 000, the range was from a low of 3313 in January to 54 161 in August. Similarly, the Port Jefferson service, with an average patronage of 18 725, shows a low of 4449 in October and a high of 31 255 in August.

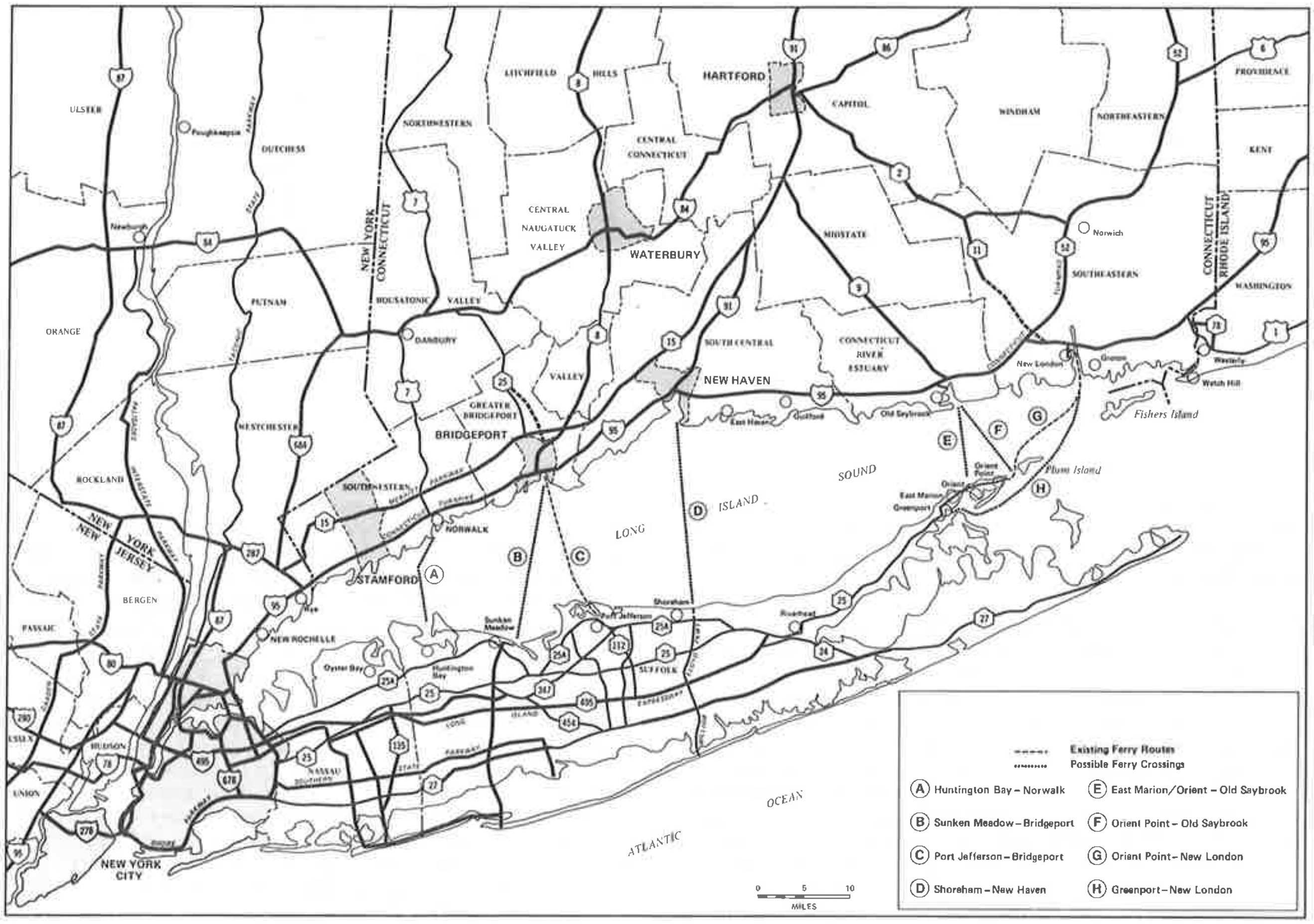
During the summer of 1980, a survey of ferry riders was conducted. The results indicate the following:

1. For both services, the largest share of riders--approximately 45 percent--lived in New York State.
2. The primary reason for using the ferry lines was to travel to and from recreational activities.
3. Automobile was the most popular means of travel to the ferry.
4. The average vehicle occupancy was 2.62 persons on the Orient Point-New London line and 2.32 on the Port Jefferson-Bridgeport line.
5. The majority of passengers began and ended their trip in either southeastern Suffolk County or Connecticut.
6. When passengers were asked what they liked about the ferry, most responded that it saved time. Other common answers were that they enjoyed the trip and that the trip saved money.
7. When passengers were asked what they disliked about the ferry service, the most common complaints concerned the cost, congestion at the terminal access, and infrequent service.

Ferry Locations

The principal alternatives for ferry-service corridors and terminal locations have been widely established over a decade or more of cross-Sound transportation improvement studies and public discussions and by the geographic location of natural harbors, urban concentration, or on-land access facilities already in place. Although detailed subalternatives may be considered further for implementation purposes, there are essentially 11 cross-Sound ferry-service corridor or terminal location alternatives (Figure 1).

Figure 1. Existing and possible ferry-service crossings between Long Island and Connecticut.



Expected Ferry Use

Forecasts of use, revenue, and capital and operating costs have been developed for all potentially significant alternative cases. For each alternative case, use and revenue forecasts have been made for the following:

1. Three user groups--(a) automobiles (including light trucks and motorcycles), (b) heavy commercial trucks, and (c) passengers (including automobile drivers); and
2. Two future time periods--(a) 1983-1984 as the earliest period that services with up to four vessels could be in place on existing cross-Sound corridors or when similar new-corridor service could be initiated and (b) 1993-1994 as a point in time when full, combined cross-Sound service improvements could be accomplished and full user response to these improvements would be expected. This approach makes it possible to evaluate the service response, capacity requirements, and revenue contribution of each user group. It also permits estimation of potential near-term and longer-range cost-revenue results and investment requirements for staged improvement and financial planning.

The key element of the study method of forecasting ferry use is relative travel costs (including the value of time) for "crossing" the Sound via an existing western bridge and using the alternative ferry service. Forecasts produced are responsive to changes in service frequency, fare levels, and relative total travel costs. This involves three basic assumptions:

1. Future cross-Sound travel patterns for automobiles and passengers will be similar to those for current users of existing cross-Sound ferry services. For heavy commercial truck travel, patterns will be similar to those currently using the Triborough Bridge system and, for eastern cross-Sound corridor alternatives, to those currently using the Orient Point-New London ferry service.
2. The rate of general inflation will decline very gradually, from the 1980 annual level of about 13.3 percent to a long-term rate of 6 percent by the mid-1990s.
3. The price of gasoline and diesel fuel will rise 25 percent above the rate of general inflation between 1980 and 1985. Fuel prices are adjusted to the rate of general inflation after 1985.

The principal data available for use in the detailed development and testing of a use and revenue forecasting method are as follows:

1. Interviews of 1980 users of the two existing cross-Sound ferry services were the source for trip purposes, origins, destinations, and weighted average trip lengths.
2. Historical information for the past 10 years provided by the operators of the two existing cross-Sound ferry services included service schedules and fares, vessel capacities and speeds, and the number of automobiles and light trucks, heavy commercial trucks, and passengers that were carried. From these data additional insights on traveler perception of, and probable response to, relative levels of service, travel time, and costs could be drawn.

Table 1. Projected 1984 and 1994 costs and revenues for two existing ferry services.

			Cost ($000 000s)					Total Revenue ($000 000s)	
			Annual Operating Cost for Boats and Terminals	Annualized Capital Cost				Fare Increased at Half Inflation Rate	Fare Increased at Inflation Rate
Service	Year	No. of Boats		Boat	Terminal	Access	Total		
Port Jefferson-Bridgeport	1984	2	2.81	1.40	0.35	0.40	4.96	3.50	3.97
		3	3.34	2.10	0.35	0.40	6.19	4.29	4.86
		4	5.04	2.81	0.35	0.40	8.60	6.86	7.94
	1994	2	5.50	1.40	0.35	0.40	7.65	6.10	8.18
		3	6.54	2.10	0.35	0.40	9.39	7.50	10.13
		4	9.86	2.81	0.35	0.40	13.42	11.9	16.64
		6	14.23	4.21	0.35	0.40	19.19	17.73	25.33
		8	18.60	5.61	0.35	0.40	24.96	23.55	33.90
Orient Point-New London	1984	3	3.19	2.10	0.26	-	5.55	4.93	5.56
		4	4.59	2.81	0.26	-	7.68	6.59	7.46
	1994	3	6.27	2.10	0.26	-	8.63	8.41	11.45
		4	9.00	2.81	0.26	-	12.07	11.21	15.50
		6	13.20	4.21	0.26	-	17.67	15.72	22.26
		8	17.41	5.61	0.26	-	23.28	20.25	28.86

3. A one-day sample of heavy commercial trucks using the Triborough Bridge system in 1979 helped to identify the travel patterns and cost and time factors for such trips.

The principal relations explaining 1970-1979 cross-Sound ferry use for automobiles and passengers were quantified through regression analysis and used to forecast future use at existing--and, by extension, all alternative--cross-Sound service corridors. This approach was also used for heavy commercial truck forecasts on the eastern crossing corridor alternatives, and a relative timeand cost-based diversion approach was used to forecast truck use in general (1). Forecasts were also prepared for each crossing alternative. In each case, the existence of another crossing alternative with similar service levels is implied. Forecasts involving three coexistent ferry services, and truck diversion to these services from the Triborough Bridge route, were developed in a slightly different manner.

The principal conclusions of the study demand forecasts and analyses are as follows:

1. The principal constraint on cross-Sound travel may be the limited cross-Sound service available. Responses from all three potential user groups are estimated to increase dramatically with each increment of cross-Sound ferry service capacity provided. They also indicate that higher fare levels will not significantly dampen user response. Recent experience on both existing cross-Sound ferry services has demonstrated just this finding: Both have increased fares, added services, and gained ridership. The ridership increases at Orient Point-New London, on the order of 20 percent between 1978 and 1979, may also reflect the capacity and amenity improvements of a new "T-boat".
2. The near-term cross-Sound ferry use forecast at all crossing corridor alternatives investigated could be very large when compared with the recent 1979 use of current cross-Sound ferry services. For the four-vessel cases, 1984 forecasts show a doubling of passenger use, more than a doubling of passenger vehicles, and more than a threefold increase in heavy commercial truck use at Orient Point-New London.

Estimated Costs and User Revenues

Cost estimates were developed for access and terminal improvements (including new harbors or long piers, where necessary) and the acquisition and operation of new vessels (T-boats). Table 1 gives more detail on alternative service levels, investment cost annualizations, and fare levels for estimated results for the two existing cross-Sound ferry service corridors. (Because of the large number of alternative service combinations considered in the study, only selected examples can be given in this summary; a full exposition of the study results is given in the technical reports.) Not surprisingly, projected annual operating costs are greatest for those corridor alternatives that have the longest crossing distances and in-harbor times, and alternatives that exhibit the shortest crossing distances and in-harbor times have the lowest annual operating costs. The Orient Point-New London service is the intermediate case. Still, the range of estimated annual operating costs is not great overall: For the eight-vessel cases, the high is $20-21 million and the low is $15-16 million.

In sum, the estimates given in the table indicate that, at least in concept, many of the alternative cross-Sound ferry-service improvements examined in this study can be economically feasible private-enterprise ventures at fare levels increased at or at somewhat less than the rate of general inflation.

Additional Potential Impacts

Environmental impacts of cross-Sound ferry services and of related shore or inland facility improvements will have to be examined in detail prior to implementation. State and/or local or federal review, evaluation, and approval procedures will have to be satisfied and acceptable plans prepared to avoid or minimize potential adverse impacts.

The economic activity that might be generated by an investment in substantially improved cross-Sound ferry services was estimated by "scaling down" the same types of regional economic impacts attributed to the very much larger investments estimated to be required for a new cross-Sound bridge in the 1979 NYSDOT study. The estimates include direct economic impacts from construction and continuing impacts from improved interregional access as well as the effect of additional increases in sales expected by business (as estimated from a survey of business executives for that bridge study).

An investment of about $100 million (probably staged in a series of smaller units) was assumed for a "major improvement" in improved cross-Sound ferry services--12 new boats at $81.6 million (in 1984 dollars) and $20 million for terminals and access. This order-of-magnitude ferry-service investment would be 6-2/3 percent of the average 1979 estimates of investment required for a new bridge. Since improved ferry service would not be as fast or convenient as bridge travel, the proportional economic impacts associated with a bridge were further reduced by one-half to reflect an appropriate level of perceived, potential business sales (and investment) that might be associated with improved ferry service. The economic impact on business is estimated to be $170 million on Long Island and $50 million in Connecticut.

Public and Private Roles in Financing and Implementation

Cross-Sound ferry services at this time are primarily a matter of private-sector concern and initiative. Formal public involvement is essentially limited to federal safety and operating authority controls and general governmental concern with such matters as traffic control, municipal harbor facilities, and the environment, primarily dredging. The user demand, cost, and revenue estimates developed in this study, although subject to further testing over time, are generally encouraging for the continuing private-sector initiative in cross-Sound ferry-service improvements, financing, and operations. At the same time, potentially significant public benefits to travelers and communities on both sides of Long Island are estimated to accompany major improvements in cross-Sound ferry services, and improvements to harbor and landside transportation facilities can be seen as furthering a variety of public objectives. Public action on such improvements, careful public attention to possible environmental, community, and continuing service adequacy issues, and, most important, clear public policies with regard to cross-Sound transportation (particularly policies supportive of private-sector initiative and disavowing competitive public action) appear to be the only public commitments necessary to assist major improvements in cross-Sound ferry service.

A number of additional assistance mechanisms are available to state and local governments. On the financial side these include tax exemptions and loan or loan guarantee capabilities to directly assist private initiatives or to lower the costs and increase the potential of securing private-sector financing. Economic development programs generally, including the existing capabilities of such institutions as the Connecticut Development Authority and several industrial development agencies in Suffolk County on Long Island, may be of material aid in the light of the broad economic benefits identified. Efforts should concentrate on incentives to encourage private-sector investment in new vessels and private ownership and operation and on improving eligibility for federal support of harbor, terminal, and access improvements.

Although the findings regarding a new, or third, cross-Sound ferry service cannot be definitive, the overall weight of the evidence available indicates that such an additional service may well be both desirable and affordable in the future. A number of technical and public support issues must be thoroughly addressed, and necessary construction and other actions to implement a new service at any location cannot be initiated without additional investigation and analysis.

It is also clear that some form of continuing public organization is desirable to follow up on these implementation proposals and to provide an ongoing forum to monitor and coordinate cross-Sound ferry services and their improvement. In keeping with these findings and established public policies, this organization need not be either an operating authority or a formal bistate body. Each state should consider an organizational form, membership, and set of responsibilities best suited to its own traditions and interests. It appears to be both necessary and desirable, however, that these organizations work closely together and that such organizations provide, in their membership, for involvement of the local areas most likely to be affected by continued and improved cross-Sound ferry services.

PRINCIPAL FINDINGS AND CONCLUSIONS

1. There is strong evidence of potential cross-Sound travel demand among all groups of users (passenger vehicles, heavy commercial trucks, and passengers) that can be tapped immediately and could grow in the next decade to 10 or more times present ferry-service use, even at fare levels designed to recover most, and in some situations all, operating and investment costs.
2. A combination of crossing locations--especially with a possible third centrally located service--will provide the best potential for service improvements and traveler and economic benefits as well as the service design, implementation staging, and operational flexibility needed.
3. Although all major potential cross-Sound ferry-service corridor and terminal location alternatives were identified and examined during the course of this study, none clearly emerged, on all counts, as the most desirable alternative to pursue. However, of those alternatives, the Shoreham-New Haven corridor appears to offer the most promise for new service and should be further examined cooperatively, publicly, and in detail. To date, no strong support has been shown for any of the cross-Sound ferry-service corridor alternatives except the two currently in operation. Little public support, or technical evidence, has been found in favor of the corridor alternatives to the west of Port Jefferson-Bridgeport. If implemented, those alternatives could have a significant adverse effect on the present locally supported private ferry service between those locations. Although transportation and energy analyses indicated potential service and financial advantages for several East Marion/Orient Point-Old Saybrook ferry-service corridor locations, those alternatives have generated little public support and some opposition on Long Island and adamant opposition in Connecticut. The Greenport-New London corridor alternative does not fare well in the evaluations of ferry services.
4. Existing cross-Sound ferry services appear to be financially sound and locally well supported, and the owners are interested in proceeding with facility, equipment, and overall service improvements; those services and locations also appear to offer the most cost-effective, and certainly the most rapid, opportunities for major service improvements.
5. Although the investment needed to fully implement potentially desirable services could approach or exceed $100 million, the total call on public resources need not be substantial and may properly be shared among benefiting jurisdictions. Such investment can, and as a practical matter must, be made on an incremental basis so as to provide all parties ample opportunity to make prudent decisions in the light of more current information.
6. Private-sector financing of the major element of cross-Sound ferry-service improvements--new, modern, and efficient vessels--should be achievable; public-sector commitments should be limited to facilitating private investments and accomplishing relatively modest improvements in landside access and terminals. Removal of speculation about public action to compete with private-sector cross-Sound ferry services or to proceed eventually with a

cross-Sound bridge would eliminate a major perceived stumbling block to private-sector investment.

7. The principal costs of improved ferry service can be financed by user revenues. Thus, the best means of conducting improved ferry service and securing investment funds to improve ferry service is reliance on the private sector for operating the ferry service and for investing in that service. Public involvement would take the form of cooperation between commissioners established in each state for the purpose of coordinating efforts to improve ferry service and to ensure that a reasonable level of improved ferry service is available to the public.

On completion of the study, the New York State and Connecticut DOTs produced an executive summary report containing the official recommendations (2). The major recommendations were as follows:

1. The States of New York and Connecticut and their several directly benefiting localities should work toward a cooperative policy commitment and a cooperative public-private program of promoting major, immediate, and continuing improvements in cross-Sound ferry services to levels needed to serve transportation demand in a safe, reliable, cost-effective, and coordinated manner. Necessary steps toward enabling legislation, bistate and state-local arrangements, and detailed implementing studies, negotiations, and programming actions should be initiated immediately.
2. The recommended program should contain four key elements: (a) staged land access and terminal improvements and vessel acquisitions for the two existing Port Jefferson-Bridgeport and Orient Point-New London services to bring both of those services up to frequent, adequate year-round capabilities with amenities for automobile, passenger, and commercial truck users; (b) initiation of detailed engineering, operations, financial, and environmental studies toward implementation of a third major year-round cross-Sound ferry service route somewhere between New Haven and Shoreham; (c) creation of continuing organizations, appropriate to each of the states, charged with responsibility for conducting the examination of a third major cross Sound ferry service, monitoring services and use, making service and improvement recommendations, taking the lead role in securing private and public funding for such improvements and in negotiating assistance and service agreements, and generally providing technical, service coordination, and promotion assistance; and (d) identification of initial public funding that can serve as a catalyst for major private funding for identified improvements in ferry services and facilities.
3. Public policies with regard to cross-Sound ferry services should generally emphasize the following: (a) private-sector operation and financing of vessels, terminals, and ancillary equipment; restriction of state-local financing to general-purpose access and public facilities improvements; and maximum reliance on user charges to support improved and continued cross-Sound ferry services; (b) support of the efforts of authorized private operators in improving services, in instituting such new services as may be found feasible and desirable, and in adjusting their operations and repositioning their equipment to best meet evolving cross-Sound service requirements or opportunities; (c) careful examination of, and sensitivity to, the economic, environmental, traffic, and energy consumption elements of service improvements and operations; (d) coordination and coordinated promotion of cross-Sound ferry services between the states and their localities, among ferry-service operators, and with related transportation service or other planning and implementation programs; (e) a staged program for improvements to existing services as well as possible initiation of and improvements to a new service; and (f) clear recognition of the importance of user amenities (protection from weather, reservation systems, etc.) and specialized freight services (exclusive runs, truck consolidation services, etc.).

IMPLEMENTATION OF STUDY FINDINGS

When fully implemented, improvements in cross-Sound ferry service to meet existing and potential needs for improved ferry service between Long Island and Connecticut could cost as much as $100 million. A legislative proposal was developed in New York to provide implementation and financing procedures. It was proposed that public-sector commitments be limited to facilitating private investment and accomplishing relatively modest landside and terminal improvements at existing locations and the accomplishment of full technical impact and feasibility studies of the third coexisting service. Since the initial proposal, there has been evidence of private initiative for new-vessel financing and the proposed element regarding public loan guarantees has been withdrawn. The major elements of the current proposal are as follows:

1. An appropriation of $1.25 million is needed to improve terminal facilities and road access, primarily at Port Jefferson.
2. An appropriation of $0.5 million will be used to provide a detailed feasibility study of ferry service at a third location. This would be a consultant effort, to be undertaken while service improvements are made and promoted and demand response is observed for existing services.

Creation of a Commission was also proposed in the legislation. This Commission will provide a mechanism for overseeing and promoting New York's interest in improving ferry services: in taking the lead responsibility in seeking private (and possibly federal) financial aid and local or state assistance; and in examining and monitoring service levels and recommending future improvements. Commission members would be from Long Island, which places the public-interest responsibility for cross-Sound ferry service with the localities that would be the principal beneficiaries of improved service. NYSDOT would also be authorized to coordinate efforts for ferry-service improvements with the Commission.

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High-Speed Commuter Ferry Service: The Boston Experience

KEITH W. FORSTALL

High-speed over-the-water passenger transportation is a relatively untested concept in the United States, although it has enjoyed wider application in other parts of the world. Therefore, it is useful to observe the limited use of this mode in the United States as one way of understanding the problems and opportunities that might be associated with expanded use of this transportation mode at other U.S. sites. A Boston demonstration with a high-speed hovercraft vessel is particularly instructive in this respect because the vessel was put in service for the urban commuter market in combination with conventional ferry service. The demonstration showed that high-speed waterborne commuter services may have great potential. However, some specific local problems kept the Boston service from realizing its full potential. A key difficulty was the limited scope of the project, including limited availability of suitable high-speed craft, which rendered it difficult to make adequate provisions for maintenance and backup service. These constraints resulted in problems of service reliability that diminished public acceptance of the service and led to its ultimate termination.

Although there have been ferries in one form or another operating in Boston harbor since the 1600s, the present move to provide commuter service between downtown Boston and the South Shore began around 1973. Over the next two years, several studies were conducted, largely at the instigation of South Shore residents. As a result, service was finally provided on a steady basis in 1977. The service consisted of one morning and afternoon trip each weekday with a conventional boat. Ridership was about 125 round trips/day.

In 1978, the Massachusetts Executive Office of Transportation and Construction (EOTC) and the Department of Public Works (DPW) bought a 60-passenger Hovermarine HM-2 Mark III for $450 000 and named it the "Yankee Skimmer". The hovercraft and conventional vessel service operated on route A shown in Figure 1, a distance of approximately 10 miles. The conventional ferry service between Hingham and Boston was provided by a 15-knot conventional-hull vessel named the "Freedom". The principal communities served are Hingham, Weymouth, Cohasset, and Quincy; the nearby communities of Marshfield, Hull, and Norwell contribute marginally to ridership. Additional over-the-water service with another conventional boat was provided by a private, unsubsidized operator on route B.

The South Shore terminal is located at Hingham Shipyard, 0.5 mile off MA-3a (Figure 1). It is convenient to Hingham and Weymouth residents, who can generally reach the site within 10 min. The terminal has approximately 250 parking spaces. There is one bus route that can provide feeder service.

Central Wharf is used as the docking site in Boston. The Aquarium stop on the Massachusetts Bay Transportation Authority (MBTA) Blue Line subway is adjacent to Central Wharf. This heavy rail line has rush-hour headways of 5 min. Bus service is provided at Central Wharf but does not offer any downtown distribution. Much of the Boston central business district is within a 10- to 12-min walk of Central Wharf.

Both the Hingham Shipyard terminal and Central Wharf in Boston lack adequate covered waiting areas, information and ticket booths, and restrooms.

In late January 1979, the Yankee Skimmer service was discontinued due to a freeze-up in the lower harbor and mechanical problems with the boat. Service was not resumed until late spring, in part because of concern over the budget available to cover operating deficits of both the hovercraft and the conventional vessel.

From May through late October 1979, hovercraft service was resumed and experienced better ridership and fewer breakdowns. The increased ridership during the summer can be attributed to the combined effects of better weather, better service reliability, and the gasoline shortage. At its peak, the commuter service was operating at capacity on two hovercraft runs each rush hour. An extra stop in East Boston was added on one of the hovercraft runs each way to service Bethlehem Steel, which bought 25 seats for that trip. In July 1979, Sunday service was offered to the Boston Harbor islands on four successive weekends and was also heavily patronized.

In the fall of 1979, there was concern at EOTC about the Yankee Skimmer's ability to perform satisfactorily throughout the winter. Service was therefore discontinued that winter and did not begin again until late in the summer of 1980. EOTC operated the vessel briefly in the fall of 1980 before selling it back to Hovermarine in December 1980. This paper is based only on the service provided through the winter lay-up in October 1979.

MARKETING AND FARE POLICY

There was little advance marketing of the hovercraft service and no paid advertising. However, because of the unique aspects of the demonstration, there were a number of news articles in Boston and South Shore newspapers when service began. In addition, since much of the ridership came from a dedicated group of "boat buffs", word-of-mouth communication was expected to be effective. In any case, since the HM-2 could only carry 180-240 passengers/peak, little advertising was considered necessary to get adequate ridership response.

After service began, information on service cancellations was broadcast on a local South Shore radio station and a major Boston station. Decisions on cancellations due to weather were usually made at about 4:00 a.m. to permit adequate notice. Commuters could also call the boat operator or EOTC for information on service status.

The tight core of regular riders lent itself to two other forms of unusual information dissemination. For several months a monthly newsletter was handed out on the boat. In addition, EOTC held periodic meetings (roughly one per month) with commuters to promote a dialogue on how the service was responding to passenger needs. These meetings were held downtown during weekday lunch hours and typically attracted about 20 riders.

The fare on the Yankee Skimmer and the Freedom was set at the same price. Initially, the one-way fare was $1.50; during the course of the project it was raised to $1.75.

Because the Yankee Skimmer was limited to a seating capacity of 60 passengers, a specific ticket-sales policy had to be developed. This is not necessary for the Freedom, which has a rated capacity of 399 persons (on the Freedom, the seats are not built in and, unlike on the HM-2, standing is permitted). Tickets were sold on a preannounced day at

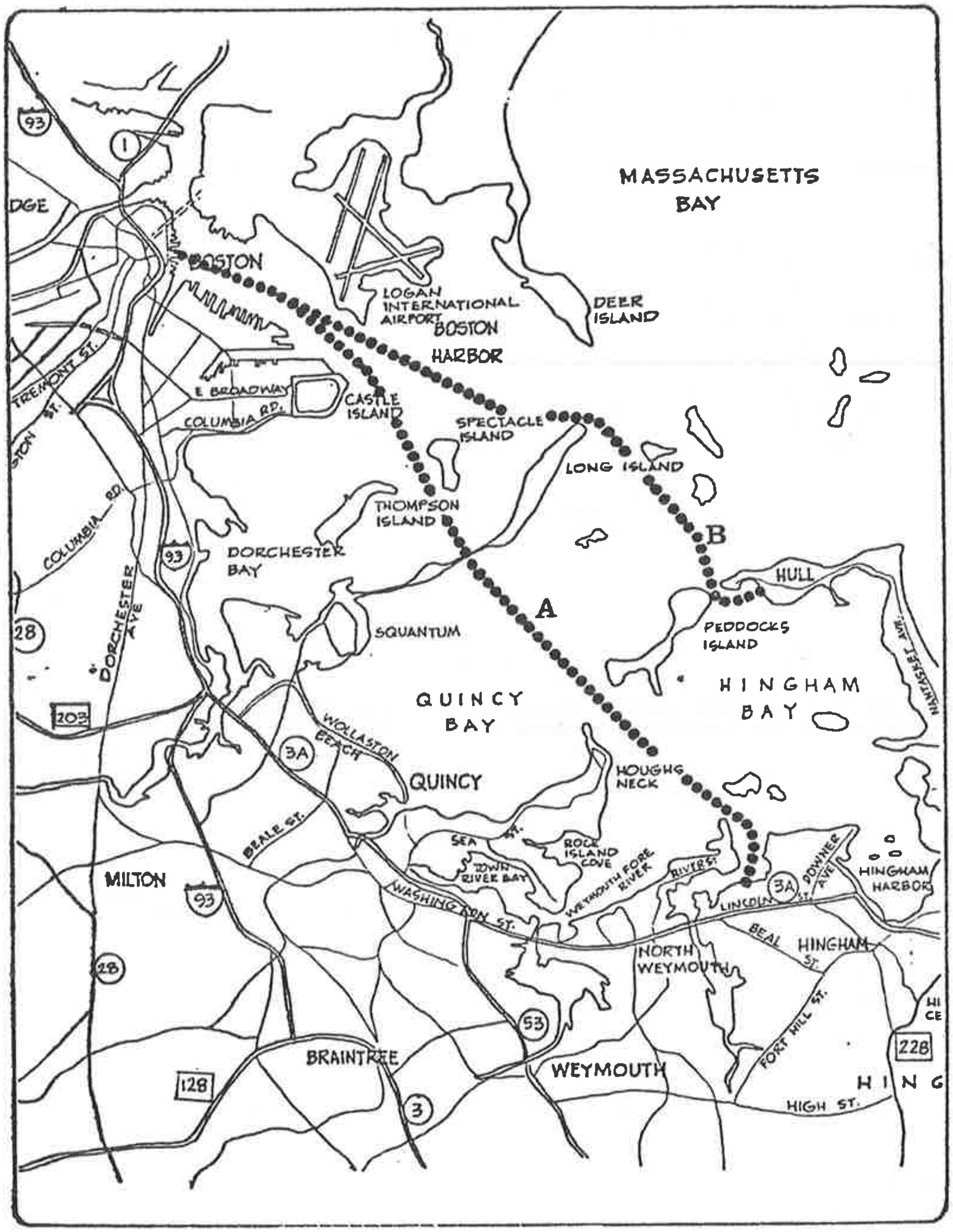

Figure 1. Project area.

the Hingham dock. Tickets were sold for specific individual trips to permit riders to select the most appropriate combination of morning and afternoon runs (or to choose to use the hovercraft in only one direction). The number of reserved-seat tickets sold varied during the project from 45 to 50 out of the 60 seats available on each run. Commuters appeared to prefer sale of as many reserved-seat passes as possible, since few of them were willing to stand in line daily. Waiting in line was not only a nuisance but was also very risky, since there were at most 15 open seats.

SERVICE RELIABILITY

Perhaps the most significant level-of-service impact in this project relates to the reliability of the hovercraft and, in turn, the reliability of the service itself. Reliability relates to the ability of the vessel both to stay in service and to maintain its published schedule. Based on a survey of passengers conducted in August 1979, reliability was considered by South Shore passengers to be one of the three most important service issues, the others being speed and frequency of service.

Mechanical and Hull Reliability

During the six weeks between the scheduled start of service on December 18, 1978, and the formal withdrawal of the hovercraft from service at the end of the week of January 22, 1979, 30 runs (three days of service) were missed because of repairs resulting from damage caused by hitting debris. This represents 16.4 percent of the 183 scheduled runs during the period.

Although it is generally believed that impacts by objects took place several times a week, the vessel's deflection system prevented damage in most cases. The operator observed that strikes were most likely on the first run in the morning before full light. Ironically, the lack of traffic in the harbor at that hour compounds the problem of darkness. When objects are observed by vessels, they are often reported on the radio, which allows other operators to be alert for them and to track them during the day. On the hovercraft's first trip of the morning, however, debris had usually not yet been reported.

Striking objects caused major damage to the hull itself on only one occasion, when it was holed in the first month of service. A more frequent result was damage to the rudders or propellers. Damage or loss of rudders was accelerated by electrolysis to the rudder bolts and posts. This problem has been diminished by installing anodes on the hulls of newer Hovermarine models.

Most mechanical problems did not result in significant downtime, partly because the HM-2 is powered by three diesel engines of proven reliability. However, there are two factors that affect the service reliability of this equipment. First, the engines are run at a higher number of revolutions per minute than is apparently normal for diesel engines, even though the operator usually ran the vessel at 27-28 knots instead of the 31-32 possible. This increased average run times accordingly.

The second mechanical reliability factor involves the principle of redundancy. Although the Freedom has four engines, it often runs on only two (to save fuel) and is still able to operate on schedule. The Yankee Skimmer can operate on one engine if necessary but does not steer well on "cushion". With drive from only one propeller, the rudders must resist a great deal of turning moment, which makes operation at normal cruise speed hazardous.

Subfreezing temperatures reduced the reliability of the hovercraft for two reasons. First, spray thrown up by the bow tended to land on the stern and freeze. This increased the weight of the vessel, imbalanced it so that air escaped from the cushion at the bow, and forced slower operating speeds. Second, problems with the cooling system developed on several occasions. On particularly cold days, a thin film of ice would develop on the surface of the water. This ice would be scooped up into the raw-water cooling system, where it would clog the filters and stop the flow of raw water through the cooling system. This caused the engine to overheat. Hovermarine engineers felt that the only solution would be to convert to an air-cooled engine, since modifications to the water-cooled systems have been judged infeasible (a deeper intake would be too vulnerable to damage and no amount of heat at the filter could melt incoming ice fast enough). Hovermarine indicated that this problem is unique to Boston among the 70 or so sites where Hovermarine vessels are in service (Rotterdam is the site closest to Boston in climate among other locations where Hovermarines operate; however, the protected waters and freshwater rivers along the Yankee Skimmer's route increase the ability of ice to form on the surface).

Schedule Reliability

The impact of weather on the hovercraft service was profound. In addition to the mechanical problems caused by darkness and subfreezing temperatures, fog occasionally reduced visibility severely enough to force slower operation. The major weather problem, however, was high winds and seas, particularly in winter. Based on a limited period of six weeks from the planned start of service to formal withdrawal of the hovercraft for the remainder of the winter season, 32 trips were canceled due to bad weather, or 17.5 percent of all trips. In contrast, between May and October only four trips, or about 0.5 percent of all trips, were canceled due to weather.

The trip cancellations due to weather are the result of U.S. Coast Guard safety regulations that were incorporated into a Letter of Stability issued for the Skimmer. These regulations prohibit service under any of the following conditions:

1. Sustained winds in excess of 30 knots,
2. Gusts in excess of 35 knots, or
3. Seas in excess of 4.5 ft.

For seas approaching 4.5 ft, the Coast Guard established a sliding scale of maximum speed guidelines. However, it was the wind restrictions rather than the wave restrictions that forced several cancellations of service. The wind restrictions were apparently imposed because of concern that in a strong crosswind the Skimmer's bow would be blown downwind due to the boat's limited water resistance while on cushion (water resistance at the stern is provided by the rudders). The Coast Guard's concern was that, with a hard offsetting rudder correction to maintain a straight course under such conditions, altering course to windward would be impossible.

By contrast, the Freedom is capable of operating in winds up to 60 knots. The Freedom did not have to cancel service due to weather during the course of the project, although a substitute boat was occasionally used.

The schedule allowed a 30-min period for each one-way trip by the hovercraft. This was based on an expectation of 20 min for the trip itself from cast-off to tie-up, 2-3 min for loading and unloading, and a layover cushion of 7-8 min. In actual practice, EOTC determined that trips departed 3.2 min late on average and arrived 28.4 min after the scheduled departure time. This implies that a slightly longer layover between trips would have prevented marginal delays on individual runs from affecting schedule adherence on subsequent trips.

Reliability Summary and Comparison

During the six-week start-up period of winter operation (December 18, 1979, to January 26, 1980), EOTC reported operating a total of 113 runs out of 183 that were scheduled, or 61.7 percent. Overall, EOTC accounted for the scheduled runs as follows (1, p. 20):

Category	Percentage
Run	61.7
Missed	
Weather	17.5
Hull damage	16.4
Mechanical problems	4.4

During the period from May 1 to October 12, 1979, service reliability improved somewhat. At its best, the hovercraft was available for scheduled service 97.8 percent of the time between June 4 and July 27. However, as a result of wear and tear this declined to 78 percent between August 6 and October 12 (1, p. 21). Overall, the Yankee Skimmer failed to operate at least some of its scheduled service in 14 out of 24 weeks of service between May and October.

SERVICE QUALITY

Four major attributes of service quality are germane to the South Shore hovercraft vessel. These include

(a) speed, (b) frequency of service, (c) ride quality, and (d) on-board amenities. Of these, speed and frequency of service were judged by riders to be the most important.

Speed

The Yankee Skimmer has a maximum speed of 31-32 knots, but it is normally operated at only about 80 percent of power to ease the strain on the engines and reduce fuel consumption. The cruising speed is therefore only 27-28 knots under normal circumstances.

Speeds may also be affected by the need to slow down for (a) harbor speed limits, (b) navigating tight turns in channels or congested harbor traffic, (c) reducing the wake in the presence of small craft, and (d) navigating in reduced visibility. There is a 6-mph speed limit in the approaches to the docks at Boston and Hingham. This restriction, as well as the problems of harbor traffic and reduced visibility, affects all craft, although the impact is more substantial on higher-speed craft. The problem of wake, however, is less significant for a hovercraft because the vessel produces a very small wake when on cushion regardless of speed, which is an advantage over conventional hull craft.

The EOTC on-board survey polled passengers on their attitudes regarding speed. Some 68 percent of Yankee Skimmer passengers rated speed as very important; only 39 percent of Freedom passengers felt the same way. All Yankee Skimmer passengers rated the hovercraft's speed as satisfactory. In fact, the EOTC report concluded that hovercraft passengers would be willing to accept a slightly longer travel time in exchange for improved reliability. Thus, it appears that a number of passengers felt that the loss of reliability offset some of the benefits of reduced travel time.

Frequency of Service

The South Shore service operated only one round trip each peak period before the Yankee Skimmer was introduced into service. Because of its higher speed, the hovercraft could just about maintain a round-trip schedule every hour. By providing three additional trips each peak period, the Yankee Skimmer substantially improved the frequency of service available with a single vessel as well as that of the overall (combined) service.

Seventy-nine percent of EOTC on-board respondents felt that frequency of service was very important and that the schedule of four trips over a 3-h peak period was satisfactory.

An important benefit of frequent transit service in general is to reduce the penalty of missing a particular trip. Unfortunately, the 1-h hovercraft headways are not helpful in this respect. Moreover, during July and August the demand for service was so heavy that, even if a commuter was willing to wait for the next run, there was no guarantee that a seat would be available.

Ride Quality

No detailed analysis of ride quality was possible as part of this evaluation. However, among hovercraft riders, the EOTC survey found that 91 percent of the passengers considered ride comfort satisfactory. This compared with 93 percent satisfaction among riders on the conventional boat. Unfortunately, no study could be conducted of those who ceased using the service. In addition, the survey was conducted in late August, which was a month without much bad weather.

On-Board Amenities

The EOTC survey asked passengers on both the Yankee Skimmer and the Freedom how important they thought it was to have coffee, snacks, or cocktails available. The Yankee Skimmer does not have these amenities but the Freedom does. Therefore, it is not surprising that three out of four Freedom passengers viewed coffee, snacks, or cocktails as important whereas only one in three Yankee Skimmer riders felt this way. Passengers may view amenities as less important on the hovercraft because the trip takes less time.

A related indication of the significance of on-board amenities is that many persons who took the Yankee Skimmer to Boston in the morning apparently took the Freedom home in the afternoon, particularly during the summer. This suggests that, whereas speed and schedule convenience may be the most desirable service-quality attributes in the morning, riders may be less concerned with these issues in the afternoon than they are with the ability to stand on deck and relax with a drink.

RIDERSHIP

Ridership on the hovercraft during the winter was moderate at the beginning of service and deteriorated, probably due to the extensive difficulties encountered in keeping the vessel in service. After service resumed in the spring of 1979, ridership was about the same as it had been at the termination of service in January, but it grew quickly. Three factors probably combined to bring this about:

1. The better weather may have made the service seem more attractive.
2. Service reliability improved markedly.
3. This was the period during which the gasoline shortage developed to crisis proportions.

Although exact figures are not readily available, EOTC indicated that ridership declined somewhat in the autumn of 1979 from the summer peak. Presumably this deterioration was due to a combination of factors, including reduced reliability, poorer weather, and the increased availability of gasoline. Reliability problems tended to develop due to the lack of time for preventive maintenance. The decreased availability of gasoline caused a marked upswing in ridership for all types of public transit (including the Freedom, which was serving 150-200 passengers/day, or about 50 more than normal), and a subsequent slippage in patronage would be expected. In addition, some riders were attracted to the service because of its novelty, which may have begun to wear off. Finally, regular riders knew the boat was going out of service for the winter and probably began to resort to other modes in anticipation.

The total average morning ridership was 175 compared with only 140 afternoon daily riders during the same period. Assuming the difference is picked up by the Freedom, this supports the hypothesis that afternoon riders are less concerned with speed and more concerned with amenities. Twice as many riders surveyed (22) reported using the Yankee Skimmer in the morning and the Freedom in the afternoon as reported the reverse.

Before the introduction of the Yankee Skimmer, service was available on one run each way per day, with a boat similar to the Freedom. Ridership on that service averaged roughly 125 passengers/day each way and remained relatively constant on the Freedom despite the added hovercraft runs. Therefore, the 150 or so daily passengers served each way

Table 1. Hovercraft project costs.

Item	Per Week ($)	Per Year ($)
Capital/start-up costs		
Depreciation		108 000
Central wharf		
Dock[a]		0
Renovation[b]		13 500
Hingham dock[b]		7 500
Crew training and boat preparation		19 500
Total		148 500
Fixed annual costs		
EOTC administration		15 000
Mass Bay Lines fee	216	11 232
Insurance		32 000
Hingham pier rental[c]		4 800
Total		63 032
Operating costs		
Crew	852	44 304
Fuel	695	36 140
Maintenance	547	28 444
Extraordinary maintenance		12 000
Miscellaneous[d]	97	5 044
Total		125 932
Total		337 464

[a] Owned by EOTC; no depreciation estimate.
[b] Paid as annual rental for two years.
[c] Excludes $4800 attributed to Freedom.
[d] Security guard and trash pickup at Hingham.

by the Yankee Skimmer appear to represent 100 percent induced ridership.

Most hovercraft riders came from one of four communities bordering the location of the South Shore terminal. This was also true before the Yankee Skimmer entered service. The greatest gains in ridership on the new service were from the communities closest to the wharf. This is logical, since benefits of reduced line-haul time are most significant for those with the shortest access time.

The principal alternative modes available to potential hovercraft passengers are the private automobile, the Red Line subway, and a private bus line. In the 1979 survey, more than 90 percent of both conventional and hovercraft passengers indicated one of these options. Since the survey did not ask any information regarding former mode, it must be assumed that responses to the question about the mode used "if boat service were not available" are representative of users' former modal choices.

Only 3 percent of the respondents to the 1979 survey (combined hovercraft and regular-service passengers) indicated that they would not have traveled if the boat service were not available. Thus, the commuter boat service did not generate significant additional travel.

Door-to-door travel times by alternative modes depend on each individual's origin and destination, so it is difficult to estimate the precise impact of the hovercraft's shorter dock-to-dock trip time. However, the table below gives some indication of how the Yankee Skimmer and the Freedom probably compare with alternative modes for passengers in the Hingham area:

Mode	One-Way Travel Time (min)	Round-Trip Out-of-Pocket Costs ($)
Drive alone	45	5.50
Drive to subway	50	2.00
Bus to subway	60	2.00
Bus	55	3.00
Carpool (two occupants)	55	2.75
Yankee Skimmer	55	3.25
Freedom	85	3.25

(The $2.00 cost for drive to subway and bus to subway is for 1978-1979; subway fares have increased since then.) Although these figures are approximate, they clearly point to the significance of the Yankee Skimmer's faster travel time. This makes the hovercraft service competitive with most other modes with respect to travel time. The conventional boat, on the other hand, simply cannot offer travel times comparable to those of other modes for the majority of commuters even in the Hingham area.

The price of the hovercraft service is generally competitive with the price of bus and carpool, but the subway offers a cheaper alternative. For those who rely on kiss-and-ride, the subway is also more reliable, runs much more frequently, and offers several convenient stops throughout the downtown area instead of only one.

Two of these three advantages over the hovercraft (reliability and frequency of service) are primarily due to the fact that it has no sister ship(s) for backup. In the long run, a more difficult issue in designing a commuter boat service is the location of docking terminals with convenient access to a substantial ridership market.

COST AND REVENUE

The projected annual cost of keeping the Yankee Skimmer in service, excluding start-up costs and depreciation, is approximately $189 000. Start-up costs were an additional $61 500 and capital depreciation of the Yankee Skimmer would have been $108 000 if the boat had been returned at the end of April. These costs are summarized in Table 1.

At its best, the Yankee Skimmer was handling approximately 322 trips/day. Average ridership is unlikely to match this primarily because of seasonal variations. With 60 percent of seats sold in the peak direction, one rider per run on the backhaul, and a 95 percent in-service record, the hovercraft would serve about 62 000 passengers annually. This would yield a total revenue of $94 000. The total deficit for the year in this instance would be $95 000, or $1.53/passenger, excluding depreciation and start-up costs. This compares with a deficit of $0.97/passenger on the MBTA bus and rapid transit service and $2.96 on their commuter rail service during the same period (1, p. 8).

It is unrealistic to absorb all depreciation and start-up costs over only two years. Assuming instead an amortization period of five years yields an estimated total annualized deficit of $166 300, or $2.68/passenger. It must be remembered, however, that other noncommuter uses of the boat might reduce the relative impact of depreciation.

REGULATORY ISSUES

Two sources of regulation significantly affected the project. The Coast Guard operating rules concerning suspension of operations in bad weather have already been mentioned; the other important regulation is the Jones Act.

The Jones Act is essentially a "buy American" law. Because it requires that a vessel used in intra-U.S. commercial service be built in the United States, it severely limits the number of hovercraft available for such use. Specifically, EOTC would have been unable to purchase a sister ship for the Yankee Skimmer even if it could have afforded to.

ENERGY CONSUMPTION

The HM-2 is claimed by its manufacturers to be fuel efficient because of its reduced drag when on cushion. On the other hand, the lift engine itself consumes energy, and the higher operating speeds also require more energy. The Freedom consumes on the order of 80 gal/h in commuter service compared with about 33 gal/h for the hovercraft (both at normal operating speeds). Because the hovercraft has a higher operating speed, this translates to 0.19 mile/gal for the Freedom and 0.85 mile/gal for the Yankee Skimmer.

Although the Freedom carries a larger payload, it appears to be marginally less efficient than the Yankee Skimmer on the basis of passenger miles per gallon. Based on the above numbers and prime direction loads of 125 on the Freedom and 36 on the Yankee Skimmer, the Freedom operates at 11.7 passenger miles/gal and the Skimmer at 15.3 passenger miles/gal. It should be noted, however, that the Freedom consumes substantially less fuel per mile at the lower speeds (6-8 knots) at which it runs in excursion service.

CONCLUSIONS

Analysis of the South Shore commuter boat service before and after the introduction of the HM-2 hovercraft indicates that over-the-water service must have certain attributes in order to compete with land-based modes. These attributes include speed, frequency, reliability, and convenient access. In some respects, the hovercraft improved the attributes of the South Shore service; in other respects, it did not or could not. Although it did provide trip times competitive with other transit modes while performing within the normal range of transit operating deficits, it was more constrained in the choice of terminals and hence in the number of commuters for whom access was convenient. The reliability of service was hampered by a combination of Boston weather and sea conditions and a lack of adequate maintenance.

In retrospect, many of the difficulties experienced in the Boston project are avoidable and it is to be hoped that future projects can be considerably more successful by the simple expedient of not replicating certain problems. These problems and approaches to solving them are reviewed below.

Wind Conditions

The HM-2 Mark III labors under a wind-velocity restriction imposed because of the potential impact on steering control when the craft is on cushion in a high crosswind. This restriction may be questioned in light of the obvious ability of the boat to alleviate the problem by dropping off cushion. Furthermore, other hovercraft designs or other high-speed technology craft may be less susceptible to this problem.

Sea Conditions

Because of Boston's northern latitude and the fact that the hovercraft was operating in protected estuarial waters, ice and slush scooped into the cooling system from the surface water was a chronic problem. These sea conditions are not duplicated anywhere else that the Hovermarine craft is in service, nor is it likely to be experienced in any other major port city in the United States. However, intake filtering systems or other engineering solutions could presumably be developed if necessary.

Mechanical Design

The HM-2 Mark III is an old model that does not incorporate the latest design features. For example, the lack of adequate anode plates probably contributed to several rudder failures. This design deficiency has been corrected on later Hovermarine models.

Engineering and Maintenance Resources

Tight budget restrictions forced EOTC to forgo corrective engineering and maintenance actions that could probably have overcome situations such as the intake of frozen raw-water coolant. Thus, even correctable problems sometimes went unchecked. Again, the conclusion is that there must be adequate budgeting for maintenance to ensure service reliability.

Boat Capacity

Because the HM-2 seats only 60 passengers, no strong marketing effort was possible. In fact, the ridership levels achieved (even without substantial marketing) during the summer of 1979, when the boat was running at its best, constituted a problem because those without reserved seats were being turned away. Thus, the South Shore service does not offer an accurate measure of what the ultimate market potential of this type of service might be. Larger boats with more seating, combined with an active marketing program, should be considered in future programs.

Number of Boats Available

Perhaps the single most perplexing problem in the Boston demonstration stemmed from the lack of additional hovercraft. Short of buying five new boats, which would have been prohibitively expensive for EOTC/DPW, the Yankee Skimmer was the only boat available to the state at the time. Without any comparable sister ship, the hovercraft could not offer attractive headways nor could it be withdrawn for essential preventive maintenance. This situation caused unfortunate repercussions throughout the demonstration. Clearly, future programs must give serious consideration to having an appropriate number of high-speed vessels to ensure continuity of service.

In view of the constraints imposed by reliance on a single high-speed craft, EOTC staff feel that the HM-2 has performed as well as can be expected. Despite the resulting limitations of the Boston-South Shore demonstration, high-speed over-the-water technology offers the promise of significantly more successful results in subsequent commuter service applications.

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New York Ports and the Expanding Coal Markets

FRANK A. McEVOY

A great amount of attention in recent port development plans has been focused on the probability of increased coal traffic. Based on this potential, various projects to inaugurate or expand coal services have been initiated at many locations throughout the United States. Recent proposed coal transportation developments at port facilities in New York State are reviewed, and the potential for increased traffic through the state is examined.

The U.S. share of the world coal market has risen steadily over the past several years along with a dramatic increase in exports of steam coal. Current projections from a variety of sources indicate the probability of continued growth in both the export trade and domestic use. It has often been noted that this coal "boom" will not achieve its full potential without major upgrading of the transportation system that serves the market. Currently, the major portion of U.S. coal shipments is handled by a few ports. Various port operators in New York State and around the United States, recognizing the potential for further market expansion, have developed plans for transshipment terminals to serve the demand.

Plans are currently under consideration for two separate terminals in New York Harbor. The Port Authority of New York and New Jersey is advancing a project that would enable it to initially handle 10 million tons/year for the export and domestic markets. The City of New York Department of Ports and Terminals has developed plans for a facility on Staten Island that would use a short slurry system to minimize environmental impacts of coal handling in an urban area. On the Great Lakes, the Port of Buffalo hopes to use its location to serve coal exports through the St. Lawrence Seaway.

At the Port of Albany on the Hudson River, a privately held Dallas, Texas, energy company has announced a plan to export up to 2 million tons/year of coal through a newly constructed facility, and the Atlantic Cement Company of Ravena, just south of Albany on the Hudson, has already used its existing conveyor system to load several vessels for export in 1981.

Since increasing use of coal has become a reality overseas, coal buyers have looked to the United States to fill gaps in supply resulting from uncertain output by more traditional producers, especially Poland. Transportation service improvements are required to meet this demand, and the ports of New York are moving to secure a share of the market.

ISSUES IN COAL TRANSPORTATION

Transporting coal for export requires a complex multimodal network linking supply centers and inland or coastal transshipment points. The capacity of the existing system has generated substantial debate in recent years. This discussion has centered on several important points.

The issue of long waiting times and high demurrage costs at primary loading ports such as Hampton Roads and Baltimore has been effectively resolved through vessel preregistration systems implemented by the railroads that operate those facilities. The long-term problem of terminal capacity has been examined closely, and some assumptions have recently been called into question. As reported in the New York Times in December 1980, it was the opinion of President Carter's Coal Export Task Force that "by 1983 at the latest there will be more than enough [capacity] to handle any possible demand", precluding further long delays for loading.

The inability of U.S. ports to handle large coal carriers (125 000 deadweight tons or more) has been the subject of much discussion. Several bills now pending in Congress are seeking to speed up dredging of deep-draft ports by recovering at least part of the cost from local entities and revising the U.S. Army Corps of Engineers permit process. The issue of cost recovery for dredging has created a great amount of controversy and, although a consensus on the need for "fast tracking" of permits has developed, it is difficult to predict the shape of the final legislation. The present depressed market for freight carriage by sea has contributed to the cost-effectiveness of smaller panamax or handy-sized vessels, at least for the short term. Although this raises doubt about the overall cost-effectiveness of deep-draft dredging projects in this period, it is probable that these projects will be pursued due to the potential savings offered by larger vessels in a strong market. Charter rates in the bulk carrier market dropped to a two-year low in 1981, and it appears that there will be little improvement in 1982. Even significant growth in the coal trade is not likely to absorb the excess tonnage. It was recently noted that orders placed for new bulk carriers in the period July-September 1981 were almost entirely for vessels of 70 000 deadweight tons or less (1). Although the market has appeared to bottom out, significant new carrying capacity to be added over the next three years suggests that the situation (for carriers) may worsen before it improves.

The outlook for the railroads is somewhat more optimistic. The rail transportation service required for even a moderate-sized export facility places substantial demands on carriers. Operation of a 10 million-ton/year facility would require three unit trains of 100 cars/day. Since unloading time is estimated at 3-4 h, operation around the clock may be necessary.

Examination of the present coal-handling market shows the obvious--that ports that enjoy proximity to supply sources currently handle the greatest percentage of traffic. Hampton Roads alone accounted for almost 60 percent of U.S. export coal traffic in 1980. The projected New York facilities are planning to serve several eastern supply centers, notably western Pennsylvania and northern West Virginia. Although the land haul to projected New York facilities may be greater in some cases, it is believed that proximity to the market and efficient handling will provide competitive overall distribution costs, especially for export. New York enjoys excellent rail access, and no major problems with unit train operations are anticipated. The majority of trackage in New York State is controlled by the Consolidated Rail Corporation (Conrail), and connection with major coal-hauling lines is possible at a number of points. The future of Conrail will be effectively determined by two profitability tests in 1983. If these are passed, as is expected, the line must be sold as an entity by June 1984. Conrail has been extremely supportive of the various coal port developments in New York, since the potential for increased revenue is readily apparent.

The impact of rail carrier deregulation has been the subject of much debate since passage of the original legislation in October 1980. A petition by the Norfolk and Western Railway to exempt East and Gulf Coast coal traffic from regulation could result in higher rates, but railroad officials maintain that prices will not increase sufficiently to affect the competitiveness of U.S. coal on the world market. The proposal elicited a strong reaction from shippers, who feel that a favorable ruling could have far-reaching effects on the position of U.S. coal, already beset by high inland transportation costs.

Environmental problems associated with unit train and coal terminal operation are not expected to be an overriding concern except in the case of the proposed New York City terminal. Impacts on environmental quality include air pollution resulting from locomotive emissions and fugitive dust, noise from railcar operations and ship loading, as well as possible water pollution from coal pile runoff. It is expected that any terminal design will strive to minimize these negative effects. An evaluation of the impacts of increased coal movements in New York State was recently completed for the New York State Department of Environmental Conservation (2). This study concluded that moderate impacts on environmental quality could be anticipated but significant negative effects were not envisioned.

PLANNED COAL TERMINAL DEVELOPMENTS

New York and New Jersey

The Port Authority of New York and New Jersey has emerged as a leading proponent of coal transportation development in New York State. The initial concept for a coal transshipment terminal located in New York Harbor has been discussed since the late 1970s, and activity has stepped up in recent months.

Cargo volumes at North Atlantic ports such as New York have been decreasing, and it is believed that the surge in demand for coal exports represents an opportunity to regain some of these lost revenues. Port Authority officials have pointed out that the Port of New York and New Jersey offers several potential advantages over competitors for the coal export trade. The harbor can be dredged to a depth of 60 ft for an estimated $140 million compared with an estimated $417 million at Hampton Roads. A significant amount of land is available with direct rail access from three major coal-hauling lines. Finally, the port's proximity to European markets could result in significant savings to shippers, especially to Northern European customers. The concept of this project has received the endorsement of the States of New York and New Jersey as well as the City of New York.

In July of last year, the Port Authority received the phase 1 final report of the engineering and economic study for a coal transshipment facility in New York Harbor. Initial capacity of the planned terminal would be 10 million tons/year, with possible future expansion to 20 million tons/year. The coal will arrive in unit trains from eastern supply regions and be conveyed to a ground storage area with a planned capacity of 2 million tons. The project cost is estimated at approximately $125 million for the preferred alternative on the New Jersey side of the lower Hudson River. The Port Authority recently completed acquisition of the proposed terminal site, and further studies are progressing.

The New York City Department of Ports and Terminals has proposed a plan for a 20 million-ton/year facility at Stapleton, Staten Island. The Stapleton site was initially considered by the Port Authority, but the environmental problems associated with unit train operation outweighed the advantage of excellent deepwater access. The City proposal envisions coal storage at a rail yard on the west side of Staten Island and mixing to form a slurry. The coal would be transported via a dual pipeline system approximately 8 miles across the island to Stapleton, where it would be dewatered and loaded. The City has estimated the total cost of this facility at $100-150 million and expects private capital to finance the project. Since the Chessie System controls rail access to Staten Island, negotiation of a joint rate with Conrail will be necessary. As with the Port Authority proposal the concept of this terminal has received wide political endorsement; however, some concern about impacts on the community has been raised by residents in the area, and environmental compatibility is being stressed in design efforts.

Port of Albany

The Port of Albany is an inland tidewater port located on the Hudson River approximately 125 nautical miles north of New York City. The Hudson River is maintained at a depth of 32 ft by the Corps of Engineers as far north as Albany.

In March 1981, the Albany Port District Commission was approached by the New Amsterdam Coal Company of Dallas, Texas, concerning the possibility of constructing and operating a coal export terminal at Albany. New Amsterdam Coal is a subsidiary of R.V. Lynch and Company, a 15-year-old, privately held energy company. After initial meetings, New Amsterdam Coal entered into an agreement to lease 20 acres of port land with an option to expand to 35 acres. The site is located on the east (Rensselaer) side of the Hudson. The company indicated that it chose Albany because of the lack of congestion, good access, and available land.

Under the New Amsterdam plan, coal will move via Conrail from producing districts in western Pennsylvania and northern West Virginia. The Albany terminal would maintain an initial stockpile of 100 000 to 150 000 tons, with possible expansion to 500 000 tons of storage. A ship loading capacity of 1000 tons/h is planned. The company plans to invest $6 million to upgrade Conrail service and complete construction of the coal-handling facility and eventually to provide $0.50/ton in added revenues to the Port District.

After some initial delays in receiving environmental and dredging permits, it appears that plans are progressing. New Amsterdam Coal has retained a major New York consulting firm to complete an engineering study for the proposed terminal. The company hopes to be in operation by 1983.

Atlantic Cement Company

The Atlantic Cement Company facility in Ravena, New York, is located just south of Albany, about 110 nautical miles north of New York City. Since 1962, the company has operated an integrated cement production operation that uses the Hudson River to distribute products throughout the Eastern Seaboard. Cement was transported to vessels via a mile-long conveyor system and, through construction of a short feeder system, the company now uses that system to load coal for export. Since the spring of 1981, seven ships destined for markets in the Caribbean and Europe have been handled in this manner. The company has recently supplemented its coal sales staff to further develop this potential but does not plan significant expansion of service without long-term buyer commitments.

Port of Buffalo

The Port of Buffalo is located on the eastern end of Lake Erie, about 1500 nautical miles from the mouth of the St. Lawrence River. The port facilities are owned and operated by the Niagara Frontier Transportation Authority (NFTA). NFTA has been interested in developing a coal terminal at Buffalo since the mid-1970s. The possibility of transporting western coal east via the Great Lakes and the potential for increased demand by utilities in the region have created a great deal of interest in a Buffalo coal terminal. The feasibility of such a facility has been investigated in a number of consultant studies. Initial questions concerning the economics of using western coal in New York State were raised in a market study of the State's barge canal system conducted for the New York State Department of Transportation in 1979 (3). The study found that "no large-volume shipments of western coal are anticipated...and notwithstanding the resultant transport cost savings eastern coal remains the preferred fuel supply option for new coal fired utility installations in upstate New York." In November 1979, a feasibility study of the bulk terminal proposal was completed for NFTA (4). This study concluded that "given the current economic and regulatory climate, there does not appear to be sufficient demand to justify construction of a bulk handling transshipment facility at the Port of Buffalo." More recently, a study conducted for the Power Authority of the State of New York (5) concluded that "the long-term potential for a large coal transshipment port does not look attractive."

Because of the increasing volume of exports and crowded conditions at some Atlantic Coast ports, interest began to focus on the need for alternative export routes, including the Great Lakes-St. Lawrence Seaway System. An examination of Great Lakes coal-handling capacity and export coal potential completed by the U.S. Maritime Administration in 1980 (6) concluded that "if world coal demand continues to increase and congestion continues at East Coast ports, the Great Lakes-St. Lawrence Route will be a competitive alternative." The study further concluded that laker feeder service to ocean vessels of 100 000 deadweight tons is the most competitive route and that the ability to load vessels of this size at Quebec City is an advantage over using East Coast ports. One example of this occurred in August 1981, when six Canada Steamship self-unloaders transferred 160 000 tons of Ohio coal at Sept Isles in the Gulf of St. Lawrence. This was the largest shipment of coal ever to leave North America on one ship.

The Port of Buffalo is served by several rail lines and currently has two berths and a conveyor system capable of loading coal into 1000-ft lakers or seaway-sized ocean vessels. Loading is accomplished with a new Kolberg mobile loading system that has a loading capacity of 2200 tons/h. The port has set aside a 210-acre site with a 3 million-ton storage capacity for bulk cargo. In addition, the facility can handle up to 100 railcars and 10 barges. NFTA believes that, when fully operational, the facility will be able to handle up to 3 million tons/year.

COAL MARKET OUTLOOK

Export

Optimistic projections notwithstanding, a variety of factors will affect the growth of U.S. coal exports in the near term. The National Coal Association has expressed fear that current economic conditions, combined with a decline in oil prices, may put a damper on the short-term growth in use of U.S. coal. In general, the United States is recognized as a reasonably dependable supplier due to abundant reserves and overall political stability. Foreign coal buyers, however, have generally been unwilling to enter into long-term contracts without accompanying improvements in port facilities. Current coal prices in the United States are 20-30 percent higher than those of our closest competitors, Australia and South Africa. The disparity results from higher labor costs, longer land-haul distance, and, for some markets, longer ocean distance. Labor costs are not likely to decline due to a strong union and the higher recovery costs, especially for eastern coal. Planned improvements in transportation efficiency may have some positive effect on the overall price competitiveness of U.S. coal in the world market.

Predictions of total coal exports have been revised downward in recent months. Despite the optimistic projections of President Carter's Coal Export Task Force, a consensus seems to be forming among industry analysts that the U.S. share of the world coal trade will grow at a rate somewhat slower than initially anticipated. Coal consumption in Europe has stagnated somewhat due to the current level of stockpiles, increased availability of competitive supplies, declining oil prices, and general recession within the European Economic Community (EEC). Options put forth by a member of President Reagan's Coal Interagency Working Group indicate that overall U.S. exports to Europe will fluctuate more widely than those of other suppliers. Recent production problems experienced in Poland, a traditional supplier to the EEC, may open some additional markets to U.S. suppliers. It appears likely that as stockpiles are reduced the United States will probably get the bulk of Europe's incremental demand. The United States is currently seen as a "swing" supplier to this market.

A report prepared by the Office of Technology Assessment (7) recognizes the difficulty of accurately estimating the U.S. share of the steam coal market in the next 20 years. In large measure, the U.S. share will be determined by problems experienced by competitors in meeting the demand and the ability of the industry to surmount the problems inherent in the U.S. production-distribution system. Another recent study (8) concludes that, whereas market expansion can be anticipated, the rate, timing, and magnitude of this growth will be effectively determined as much by corporate strategies as by national energy policy.

Domestic

Although a large increase in domestic coal use has been forecast since the mid-1970s, intrinsic problems in the utility industry have prevented realization of this objective. The energy policy put forth by the Reagan Administration has emphasized the importance of free-market mechanisms to meet potential energy crises. Utilities have been hard-pressed to finance voluntary conversions due to a leveling of demand, rising fuel costs, and depressed stock prices. It is not likely that direct subsidies will come about and, with no large-scale program of conversions, it appears that domestic coal use will grow much slower than initially anticipated.

Revision of the Clean Air Act was expected to be one of the controversial issues of the 1981 congressional session. Without congressional action, the current version, enacted in 1970, will remain in effect. Progress has been extremely slow. As of late 1981, a number of proposed revisions had been offered but a consensus has yet to emerge. Large-scale relaxation of emissions standards does not appear likely at this time.

Within New York State, several utilities are examining the feasibility of conversion to coal use. Consolidated Edison of New York has extended a test burn of higher-sulfur fuel oil as a prelude to conversion at two facilities in New York City. Although real progress toward conversion has been described as "glacial", regional growth potential for this segment of the coal market is significant. If scheduled conversions are carried out, an increase in coal shipments of up to 10 million tons/year is possible. After a steady decline in the 1970s, coal consumption in New York State has begun to increase slowly. Few problems are anticipated in serving the transportation requirements of this market.

CONCLUSIONS

Proponents of coal terminals in New York State believe that a significant amount of traffic can be diverted to the proposed facilities and that total distribution costs would be competitive with other East Coast ports. Availability of land, good access by major rail carriers, proximity to the market, and, in the case of New York Harbor, a dredging cost significantly lower than dredging costs for competitor ports will, it is believed, contribute to the economic viability of the proposed terminals.

Planned project capacities at New York State ports are given below:

Port	Capacity (000 000 tons/year) Initial	Storage	Projected Start-Up Date
New York/New Jersey	10	2	1985
New York City	10	1	1985-1986
Albany	2	0.15	1983
Buffalo	1	3	1984
Hudson River	1	0.10	1981
Total	23.5	6.25	

The growth in coal use has been hailed as a means by which to achieve a variety of national objectives. The ports of New York expect to gain a share of the market and anticipate that the goals of regional development may be served as well.

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