

- Inc., Seattle, Phase 3 Rept., Jan. 1977.
5. Supplementary Report of the Highway Cost Allocation Study. 89th Congress, 1st Session, House Document 124, March 1965.
 6. Allocation of Highway Cost Responsibility and Tax

Payments, 1969. Federal Highway Administration, May 1970.

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Improving Ferry Service Across Long Island Sound

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A study of vehicle-carrying ferry service across Long Island Sound is described. The purposes of the study were (a) to consider a wide range of possible services; (b) to explore and evaluate the economic performance, environmental impacts, and economic development impacts of these services; and (c) to combine the various measures of performance into an overall measure of feasibility that could be used as a basis for making recommendations. Five types of vessels were earmarked for study, from small, conventional-displacement vessels to high-speed hovercraft. A range of volumes and several possible crossing sites were chosen. A relatively simple economic model was constructed that used as input cost and performance data for ferry vessels, crossing distances and limitations on harbor speed, site-specific terminal cost estimates, and projections of fare versus the volume of vehicles carried at each site. A computer program written for this model was run for a wide range of vehicle volumes, crossings, and vessel types. Detailed studies were made of environmental impacts and the feasibility of terminal locations for services that performed well economically. The study concludes that high-technology vessels are not economically viable for vehicle-carrying service across the Sound and recommends near-term improvements to existing services that would lead to greatly expanded services over the long term.

Travel between Long Island and New England must currently take either a long, circular route passing over congested highways and bridges in New York City or one of two relatively high-cost ferry routes, one of which operates in the summer only. A bridge study conducted in 1971 (1) was part of an early attempt to improve travel between Long Island and the mainland. The study evaluated several potential bridges at various sites on the Sound. A bridge between Rye and Oyster Bay was proposed but met with strong public opposition and was subsequently abandoned. The proposed bridges east of the Rye-Oyster Bay Bridge were ruled out from the start because their tolls would not be able to cover their costs. The New York and Connecticut Departments of Transportation then decided to consider ways of improving ferry routes and services.

This paper describes the methodology and results of a study of ferry service across Long Island Sound performed by the Tri-State Regional Planning Commission for the New York and Connecticut Departments of Transportation (2). The purpose of the study was to examine a variety of potential ferry routes and determine the costs and benefits of each route. This involved a careful analysis of ferry vessels, terminals, sites, and a range of volumes of vehicles and passengers as well as an evaluation of the impact that such a ferry service would have on the environment and on local development. The results were then combined to formulate a set of recommendations.

SERVICE CHOICES AND IMPACTS

The basic choices that must be made in setting up a ferry service and the major impacts of these choices are summarized in the following table.

Choices	Impacts
Vessels	Economic
Speed	Capital cost
Vehicle capacity	Operating cost
Turnaround time	Fare revenues
Length	Deficits
Draft	Developmental
Operating cost	Employment
Terminal sites	Population
Crossing distance	Environmental
Harbor cruise	Ferry traffic on local roads
Water depths	Terminal construction and operation
Site location	Vehicle emissions
Size of service	Energy use
Annual volume	
Peak-day volume	
Load factor	
Crossing time	
Vessels required	
Vessel hours	
Vessel berths	
Headway	

Each of the basic choices (vessels, terminal sites, and size of service) is critical in determining the economic and environmental consequences of a ferry service.

Vessels

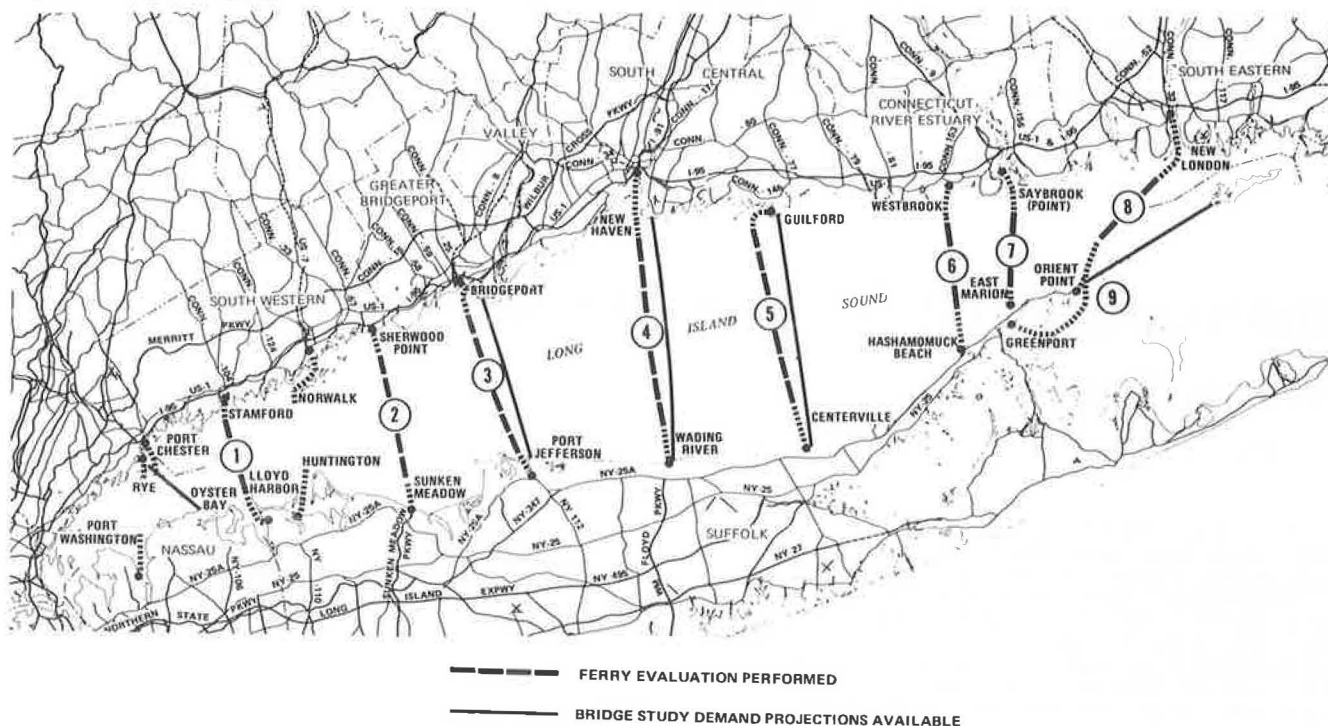
The types of vessels studied were

1. The conventional displacement vessel, which has low capital and operating costs as well as relatively low speeds and high capacities. Four vessel types were studied, including 200-vehicle, 100-vehicle, 100-vehicle used (converted from steam to diesel power), and 50-vehicle "T-boat" (designed to operate with a smaller crew).

2. The amphibious hovercraft, which floats on a cushion of air. This feature gives the vessel high speed and allows it to land directly on shore. Capital and operating costs (especially for fuel) are high as are noise-emission levels.

3. The rigid-sidewall surface effect ship, which floats on a bubble of air trapped between rigid sidewalls that pierce the water. Its costs and speed are less than those of hovercraft but more than those of a conventional-

Figure 1. Ferry crossing sites.



displacement vessel. Noise emissions are low. Surface effect ships that carry vehicles have not yet been produced.

Terminal Sites

Nine crossing sites were considered, from Stamford-Lloyd Harbor in the east to Greenport-New London at the western end of the Sound (Figure 1).

Size of Service

The study considered four annual service volumes (vehicles carried): 200 000, 500 000, 1 000 000, and 2 000 000 vehicles/year. If government support is involved, the ultimate decision on which type of ferry service to establish, if any, will most likely be based on (a) ferry economics (capital investment, operating costs, fare revenues and subsidies); (b) economic development impacts; (c) environmental impacts (local traffic and terminal construction and operation); (d) political and policy considerations; and (e) available funds and competing uses for these funds. This report examines only the first three of these decision criteria.

STUDY APPROACH

A relatively simple model was developed to determine the economic consequences of each ferry service as a function of vessel performance and cost, estimated capital cost of terminals and access roads, and revenue projections made at each site. The study approach consists of the following procedures.

1. Define service by vessel type, crossing site, and annual volume.

2. Determine service characteristics as a function of the related factors listed below (assuming a minimum service level of 13 h/d, 2-h headways, and a 14-h average service day):

Characteristic	Related Factors
Crossing time	Vessel speed, crossing distance, in-harbor cruise time
Peak-day volume	Annual volume
Vessels required	Peak-day volume, crossing time, turn-around time
Average annual load factor	Annual volume, minimum trips per day, vessel size
Vessel trips	Average annual load factor, annual volume
Vessel hours	Vessel trips, crossing time, turnaround time
Vessel berths	Peak-day trip frequency, turnaround time
Average headway	Annual volume, vessel size, average length of service day

3. Determine economic impacts as a function of the related factors listed below (assuming that ferry crossing time and wait time reduce revenue per vehicle by \$2 to \$3/h and \$3/h respectively and that annual amortization rate is 8 percent):

Impact	Related Factors
Capital costs	
Vessels	Vessels required, cost per vessel
Terminals	Water depths at site, berths required
Operating costs	
Vessels	Vessel annual costs, hourly costs, hours
Terminals	Annual volume served
Revenues and subsidies	
Fare revenue	Ferry crossing time and wait time, location of crossing site, vehicles served per year
Operating subsidy	Revenue and operating cost
Annual capital cost	Total capital cost, amortization rate

4. Evaluate other impacts by considering their related factors, as follows:

Impact	Related Factors
Developmental	Ferry volume, automobile and truck savings, desirability of growth in area of crossing site

Impact	Related Factors
Environmental	
Ferry traffic	Ferry volumes, current local conditions
Terminal construction and operation	Local site conditions, pleasure boat traffic
Energy use and pollution reduction	Ferry fuel use and emissions, fuel savings and reduced emissions for automobiles and trucks
Aesthetic and other	Local conditions, ferry facilities required

5. Summarize and compare the costs and impacts of alternate services and assess their feasibility.
6. Make recommendations.

A computer program was written for this model and run for many combinations of crossing site, vessel type, and service size. Detailed studies were then made for the most attractive services.

FINDINGS

Revenue Projections

The factors considered in predicting fares were current zone-to-zone travel (on existing bridges), time and distance saved on each ferry route, ferry fares, and existing ferry patronage. The volume of business at each ferry site is increased by reducing fares, increasing ferry speeds, or providing more frequent service. As might be expected, projected demand for ferry service at crossings farther east of the competing bridges was less elastic. The eastern crossings could charge the highest fares at low volumes, but to increase business they would have to make greater cuts in their fares than ferry services farther west.

Peaking of ferry demand also has far-reaching consequences on the economics of ferry service. The peak-day demand determines the size of the fleet required, and the greatly reduced demand at other times means that vessels lie idle or operate at far below their full capacity. It is expected that, as the size of a ferry service increases, demand will shift away from highly peaked summer vacation travel to more business and commercial travel and the peaking problem will become less severe.

Costs

The basic costs of providing ferry service are those for vessel operation—including crew, fuel, and maintenance—and terminal operation and maintenance. Vessel operating and capital costs were determined for each site and volume of service based on the cost and performance data given in Table 1. Terminal operating and maintenance costs were estimated based on recent experience on the Cape May-Lewes Ferry Service. A consultant was employed to determine the feasibility of terminals at certain locations, to develop a design concept, and to make preliminary estimates of terminal costs and environmental impacts.

An analysis of the costs of a typical service (New London-Orient Point) is shown in Figure 2. Costs and benefits for this service are itemized in the following table (assuming service volume of 200 000 vehicles/year, T-boat vessels of 50-vehicle capacity, and an annual amortization rate of 10 percent).

Item	Amount
Vessels required	5
Capital costs (\$000 000s)	
Vessels	6.9
Terminals	0
Total	6.9
Annual costs (\$000s)	
Amortization	688
Operating costs	1643
Total	2331
Annual benefits (\$000s)	
Fare revenue	2706
Consumer surplus	474
Total	3180
Projected annual profit (\$000s)	375

The benefit/cost ratio for the New London-Orient Point service (total annual benefits divided by total annual costs) is 1.36. Funds for terminals for this service are already committed by the operator and New York State. Consumer surplus, which represents the value to ferry users of their time and travel savings in addition to the fares paid, is discussed in more detail later in this paper. The total cost is about half amortization and half operating. Crossing distance is critical in determining the cost of providing service because both vessel operating costs and the number of vessels required on a given service will vary directly with the time it takes to make a round trip.

Impacts

Development

Any new transportation facility will have an impact on the area it serves. The degree of the impact increases with the number of people served by the facility and the amount of time, kilometers, and money saved by using the new facility. Businesses may expand and hire new workers because of the reduced time and cost of shipping and receiving goods. Individuals may move in to fill new jobs or may relocate because the area is now more accessible to jobs elsewhere. Development can also occur in the form of restaurants, shops, and hotels to serve travelers who use the facility.

Compared to a bridge, a ferry is a low-capital, high-operating-cost facility economically suited to carrying small volumes at relatively high tolls. Beyond a certain volume ferry fares must be lowered to a point where they do not cover the operating costs of additional service. Thus a ferry service will probably be a comparatively low-volume, high-fare facility, which will limit its impact on development.

One way to estimate the size of ferry-service impacts on development is to evaluate the consumer surplus. In economic terms, consumer surplus is the total amount of additional revenue that could be generated by charging the maximum fare that each patron would be willing to pay to use the service and is a measure of the benefits received by users of the service beyond what they pay in fares. Consumer surplus is shown in Figure 3 as the shaded area above the demand curves. Although both facilities can charge the same fare at volume V, facility B has a larger consumer surplus and its users would derive more benefits.

Environment

The aspects of ferry service that would affect the environment are terminal construction, vessel operation, and ferry traffic on local and regional roads.

Terminal Construction

The environmental impact of the construction of a ferry terminal depends on the site, the terminal design, and the construction methods used. Breakwaters and dredging, especially in an area such as the North Shore of Long Island, could block the flow of sediments, change the currents along the shore, and lead to shoaling and erosion of beaches. It was determined, however, that protective breakwaters would not be required; an open-

pile pier leading out to deep water would virtually eliminate beach erosion.

Ferry Vessel Operations

The operation of ferry vessels could interfere with local pleasure boating. If ferry docking facilities were located in an estuary or near wetlands, the propeller wash could cause the accumulation of sediment, which would be harmful to shellfish and other forms of marine life.

Table 1. Cost and performance of ferry vessels.

Type of Vessel	Capacity (automobiles)	Length (m)	Draft (m)	Cruising Speed (km/h)	Capital Cost (\$000s)	Annual Cost (\$000s)	Cost per Hour Under Way ^a (\$)	Cost per Operating Hour ^a (\$)	Turnaround Time (min)
100-vehicle displacement	100	97.2	3.0	31.5	7 480	160	80	120	25
200-vehicle displacement (double ended)	200	134.1	5.5	37.1	15 200	308	213	185	20
Surface effect ship	40	67.1	1.5	74.1	10 700	316	540	135	20
Hovercraft (SRN4)	30	39.6	0	111.2	15 400	434	530	170	20
Used steam (diesel conversion)	100	111.9	3.2	25.9	1 500	160	80	120	30
50-vehicle T-boat	50	66.1	2.4	27.8	1 375	38	31	64	20

Note: 1 m = 3.3 ft; 1 km = 0.6 mile.

^a Annual operating cost = annual cost × number of vessels + cost per hour under way × hours under way + cost per operating hour × operating hours.

Figure 2. Cost analysis for New London-Orient Point service.

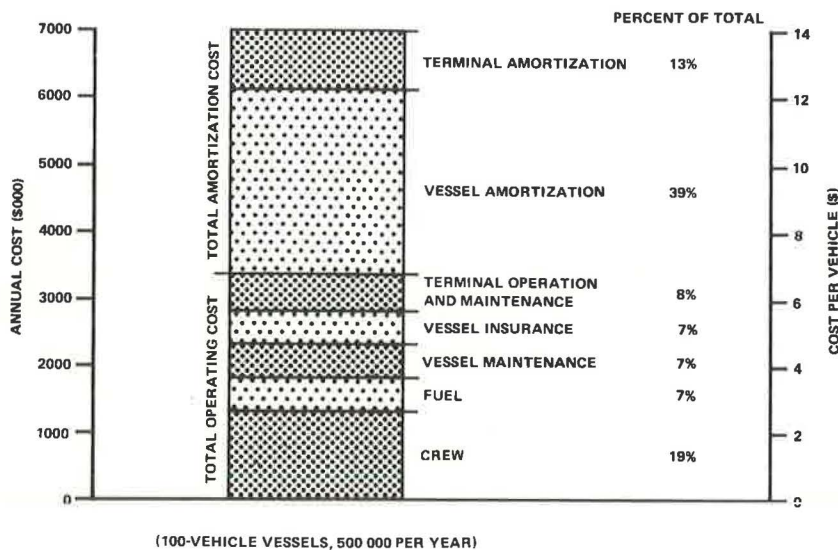
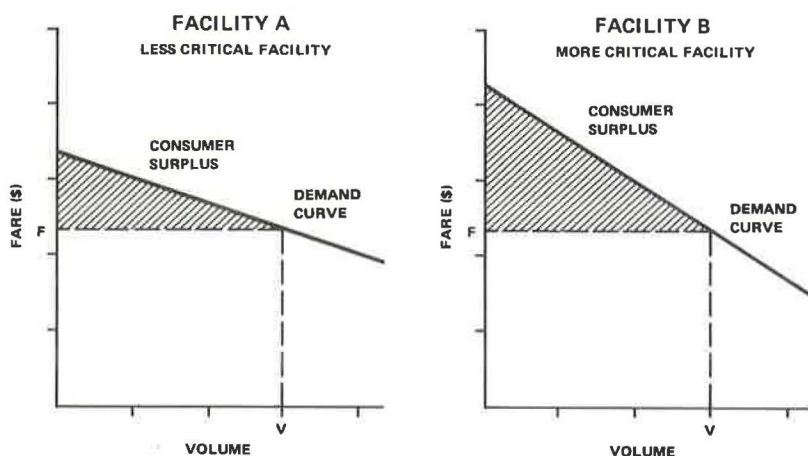


Figure 3. Consumer surplus.



This could be a factor at the Bridgeport-Fayerweather Island site and in East Marion. The other sites are not expected to be affected by propeller wash.

Ferry Traffic

The most noticeable and probably the most significant environmental impact of a ferry operation is the effect the ferry traffic has on the immediate terminal area. The traffic expected on a ferry facility is small compared to the capacity of a two-lane rural highway. Fig-

ure 4, which uses as an example traffic on open areas of NY-25 for which 1973 one-way, peak-hour volume was 365 vehicles, shows that at an annual volume of 500 000 vehicles/year the peak-day, peak-hour ferry traffic is less than half the capacity of a single lane of traffic under conditions of stable flow. The impact of the ferry traffic depends on the spare capacity available on existing roads. In this case the ferry would cause only a slight reduction in travel on the Throgs Neck and Whitestone Bridges. Even a ferry serving 2 000 000 vehicles/year would reduce the total traffic on these

Figure 4. Impact of ferry traffic on a two-lane road.

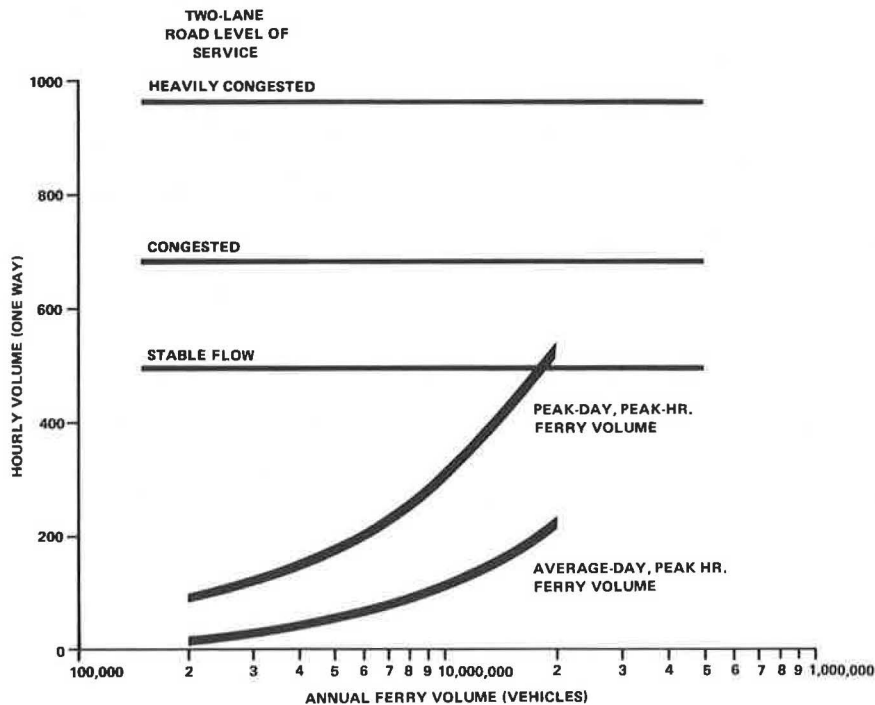
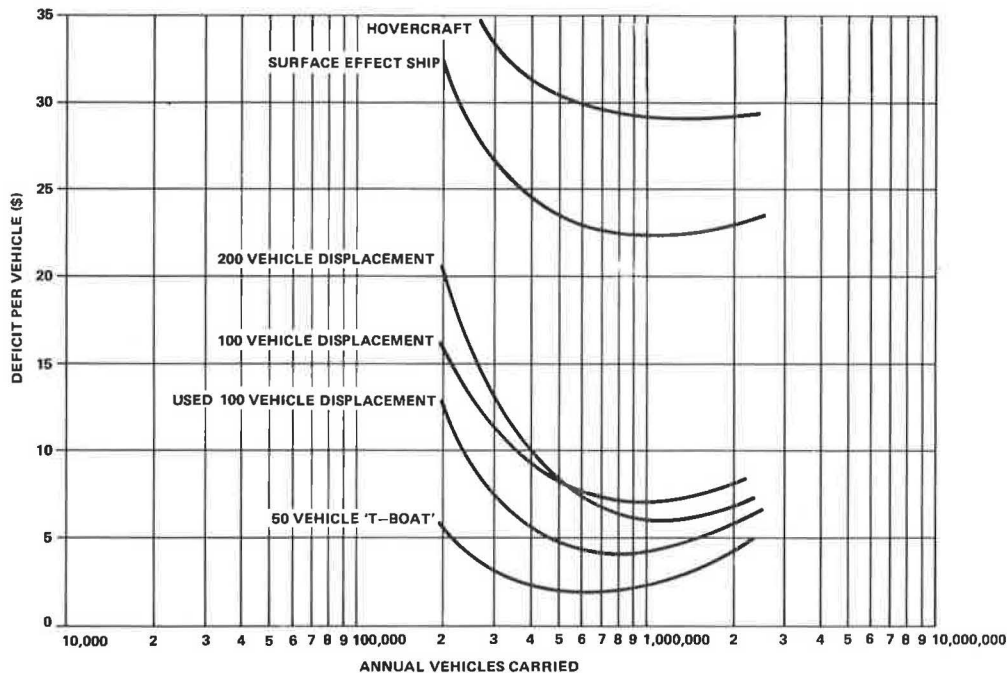


Figure 5. Deficit by type of vessel for New Haven-Wading River service.



bridges by less than 2 percent.

Air Pollution and Fuel Use

By eliminating the land trip around the Sound, a ferry service would reduce fuel use and air-pollution emissions, but the effect would be relatively small and the bulk of the reductions would occur outside the areas of highest congestion and pollution concentrations.

The high-speed surface effect ship and the hovercraft would add to fuel use and emissions because they would burn considerably more fuel per vehicle than it takes to go around the Sound.

Summary of Costs and Benefits

The subsidies required for a typical crossing are shown in Figure 5 for each of the vessel types studied. The costs and deficits for high-technology vessels—the surface effect ship and hovercraft—are much greater at all volumes than those for the conventional-displacement vessels studied. The high speeds, high fares, and high load factors projected for these more sophisticated craft are not expected to outweigh their high capital and operating costs in vehicle-carrying ferry service.

Costs and benefits of ferry services at each site are summarized in Table 2 for services using vessels of 100-vehicle capacity. By using 100-vehicle vessels, all of the ferry services are expected to cover their operating costs through fare revenues. Only one site, Westbrook-Hashamomuck, is expected to cover the amortization cost of vessels and terminals. Because of the inclusion of consumer surplus in the calculation of benefits, ferry services at Westbrook-Hashamomuck and East Marion-

Saybrook Point show benefits that are greater than their total cost. Unfortunately, the most attractive sites from an economic point of view have severe problems with land access and environmental impact.

Evaluation of Findings

A decision on implementing ferry service must take into account

1. Costs versus revenues;
2. Impact of ferry traffic on local roads and feasibility of making needed improvements;
3. Access from local roads to shorelines; and
4. Impact and feasibility of terminal location and construction.

High-speed ferry vessels were ruled out because of their poor economic performance. The conventional ferry services still being considered were compared by rating each on a scale ranging from very poor to very good. The ratings, which are based on other studies and are described briefly elsewhere (1), were then combined into an overall measure of feasibility (Table 3). This method proved to be the most practical way of combining and presenting various measures of ferry-service performance.

CONCLUSIONS AND RECOMMENDATIONS

The study reached the following major conclusions.

1. High-technology craft are extremely expensive to purchase and operate in vehicle-carrying service and

Table 2. Costs and benefits of ferry services.

Ferry	Capital Costs (\$000s)			Cost per Vehicle (\$)		Benefits per Vehicle (\$)			Annual Profits (\$000s)		Benefit/ Cost Ratio
				Oper- ating	Total	Fare Rev- enue	Con- sumer Surplus	Total	Oper- ating	Total	
	Vessel	Terminal	Total								
Stamford-Lloyd Point	28 838	11 370	40 208	5.78	12.21	6.57	2.03	8.60	398	-2818	0.70
Sunken Meadow-Sherwood Point	25 457	16 276	41 733	5.17	11.85	7.40	2.15	9.55	1116	-2223	0.81
Bridgeport-Port Jefferson (current)	32 353	9 199	41 552	6.40	13.05	7.03	2.30	9.33	312	-3012	0.71
Port Jefferson-Bridgeport (Fayerweather Island)	31 617	10 376	41 993	6.27	12.99	7.10	2.30	9.40	414	-2945	0.72
New Haven-Wading River	38 906	14 962	53 868	7.57	16.19	8.38	2.50	10.88	406	-3903	0.67
East Haven-Wading River	32 457	14 962	47 419	6.42	14.01	9.02	2.50	11.52	1298	-2495	0.82
Guilford-Centerville	31 859	14 970	46 829	6.31	13.81	10.08	2.69	12.77	1881	-1866	0.92
Westbrook Harbor-Hashamomuck	21 834	13 538	35 372	4.53	10.19	10.76	3.44	14.20	3117	287	1.39
New London-Greenport	48 053	8 400	56 453	9.20	18.24	9.44	3.44	12.88	116	-4400	0.71
East Marion-Saybrook Point	24 626	14 943	39 569	5.02	11.36	10.49	3.44	13.93	2731	-435	1.23
New London-Orient Point	34 279	10 878	45 157	6.75	13.97	9.54	3.44	12.98	1396	-2217	0.93

Note: Service volume of 500 000 vehicles/year; vessel of 100-vehicle displacement.

Table 3. Evaluation of impact and feasibility of ferry services.

Ferry	Economic Performance	Highway Access	Site Access	Terminal Location	Overall Feasibility
Stamford-Lloyd Point	Poor	Poor	Fair	Very poor	Poor
Sunken Meadow-Sherwood Point	Fair	Good	Very poor	Very poor	Very poor
Bridgeport-Port Jefferson (current)	Poor	Fair	Good	Good	Fair
Port Jefferson-Bridgeport (Fayerweather Island)	Poor	Fair	Fair	Poor	Poor
New Haven-Wading River	Poor	Very good	Fair	Fair	Poor
East Haven-Wading River	Fair	Good	Fair	Fair	Fair
Guilford-Centerville	Fair	Poor	Good	Fair	Fair
Westbrook Harbor-Hashamomuck	Good	Fair	Very poor	Very poor	Poor
New London-Greenport	Poor	Poor	Good	Good	Poor
East Marion-Saybrook Point	Good	Good	Very poor	Very poor	Poor
New London-Orient Point	Fair	Good	Good	Good	Good

Note: Service volume of 500 000 vehicles/year; vessel of 100-vehicle displacement.

would require very high subsidies in spite of their high speed, higher load factors, and higher fares as compared to displacement vessels. A fleet of 200-vehicle vessels would be more expensive to operate than smaller 100-vehicle vessels for volumes up to 1 000 000 vehicles/year. Even at the highest volumes the savings are modest.

2. At some point fares will fall below the cost of providing service and the deficits per vehicle will increase. In economic theory, ferry volume should be set at a point where the fares plus the marginal dollar value of external benefits (such as pollution and road use saved by the ferry) are equal to the marginal cost of providing ferry service. Both the fares and the marginal cost of providing service, however, are best determined in practice.

3. The relative development impacts of a ferry are projected to be small. Passengers commuting to work are not likely to use ferry service in large numbers because of the costs and time involved.

4. At most ferry sites the most significant environmental impact results from the traffic that is generated on local access roads. Peak-day, peak-hour traffic is expected to make up as much as 40 percent of the capacity of a single lane of traffic on a rural highway under relatively uncongested conditions. In some areas, however, there is not enough spare capacity on existing roads and extensive improvements are necessary. Only slight savings in fuel and emissions result from ferry use.

This study was not able to find any clearly desirable sites for large-scale ferry service. Those sites that are most desirable economically have severe problems with land access and terminal construction. The current prospects for improvements to ferry service in the private sector are excellent. The current operator of the New London-Orient Point Ferry, Cross Sound Ferry Services, has received Coast Guard approval on the design for, and has begun construction of, a 50-vehicle vessel called a T-boat, which could significantly lower the costs of providing ferry service.

Near-Term Improvements

It is recommended that the states closely monitor and provide assistance to the development of ferry service in the private sector. A relatively modest investment by the states could serve the following short-range goals:

1. Ensure reliable service,
2. Reduce fares by introducing more efficient vessels, and
3. Maintain the incentive in the private sector to hold down the cost of providing service.

New London-Orient Point

On the New London-Orient Point route, if the operating and capital costs of the T-boat vessel are as low as projected, substantial improvements in ferry service could be instituted without the need for continuing subsidies. The potential here is for a ferry service serving 200 000 vehicles/year (at higher volumes substantial improvements to land access would have to be made). Such a service is projected to be self-supporting.

Bridgeport-Port Jefferson

The current Bridgeport-Port Jefferson service operates only 4 months out of the year. This service, which operates a single, side-loading, 35-vehicle vessel, provides a round trip every 4 h but carries no trucks. A through-

loading displacement vessel and improved terminals could substantially reduce the operating costs of the service as well as reduce round-trip vessel time from 4 to 3 h.

The potential here is for a two-vessel operation carrying 50 000 vehicles/year. Congestion on local streets in Port Jefferson may prevent the service from carrying trucks. Improvements would be needed to relieve this congestion if volumes greater than 50 000 vehicles/year were to be carried. The costs of such improvements are as follows:

Item	Cost (\$000 000s)
Vessels (2 at \$1.375 million each)	2.8
Terminal improvements	0.5
Total	3.3
Annual amortization (at 10 percent)	0.33

A large portion of these costs could be financed through reductions in the operating cost of the service and through increased revenues in response to improved service.

In addition to substantially improving current service, the following measures would also aid the states in establishing a much larger service at a later date.

1. Test the T-boat design in service to determine its near-term improvement costs and performance.
2. Test the market for improved ferry services to establish more points on the demand curve for ferry service.
3. Develop the market for improved ferry service.

Long-Term Improvements

Major services appear to be feasible at four sites: Bridgeport-Port Jefferson, East Haven-Wading River, Centerville-Guilford, and New London-Orient Point. Of the four, the Bridgeport-Port Jefferson and New London-Orient Point sites are the most attractive. The costs and benefits of services at the four sites are comparable. However, services at Bridgeport and New London could be developed in stages, whereas service at either of the other sites would require the commitment of \$15 million in terminal facilities, including long piers out into the Sound, before the market for ferry service could be tested. If more than one major service were set up they would undoubtedly compete with each other. The actual volumes are best determined in practice. Based on our analysis the following combinations appear to be desirable and feasible.

Site	Annual Volume (000s)
Bridgeport-Port Jefferson	500
New London-Orient Point	200
New Haven-Wading River (or East Haven-Wading River)	500
New London-Orient Point	200
Guilford-Centerville	> 500
New London-Orient Point	500

The decision on whether to invest in ferry service depends on the availability of funds and the competing uses for these funds. An investment in a viable, large-scale ferry service is one whose value will grow through time. If the service covers its operating costs, the burden of fixed debt service payments should gradually diminish as revenues and other costs rise through inflation. In the meantime, the near-term recommendations made here can provide substantial improvements to current service at a relatively modest cost and also help to test and develop the market for a greatly expanded ferry service.

REFERENCES

1. A Comprehensive Transportation Study for Proposed Bridge Crossings. Creighton, Hamburg, Inc., and the New York State Department of Transportation, Dec. 1971.
2. Crossing the Sound: A Study of Improved Ferry Service on Long Island Sound. Tri-State Re-

gional Planning Commission, New York, Dec. 1974.

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Significance of Benefit/Cost and Cost/Effectiveness Ratios in Analyses of Traffic Safety Programs and Projects

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This paper is a critique of NCHRP Report 162, Methods for Evaluating Highway Safety Improvements. Several important conceptual errors in that publication concerning the use of benefit/cost and cost/effectiveness ratios in evaluating traffic safety programs and projects are identified and discussed. Qualitative and quantitative arguments, as well as supporting numerical examples, are provided.

In the fall of 1971 the National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board initiated a major research effort primarily funded by the American Association of State Highway Officials (AASHO). The principal objective of the study was to develop a set of guidelines detailing the methodology and techniques for evaluating the effectiveness of highway safety improvements in terms of reduced accidents. It was also expected that a methodology would be incorporated for evaluating these safety improvements by cost-benefit analysis.

The final report, NCHRP Report 162, is for the most part a well-written, useful document. But, in my view, its usefulness is markedly diminished by several serious conceptual errors concerning the proper application of benefit/cost and cost/effectiveness ratios.

FISCAL OBJECTIVES

The authors of NCHRP Report 162 point out that "the method of analysis chosen to select from among mutually exclusive improvements at a location depends upon the fiscal objective of the agency making the selection" (1, p. 8). They further assert that there are two fiscal objectives:

1. Optimum improvement, in which the goal is to obtain the most net benefit from each investment opportunity; and
2. Benefit maximization, in which the goal is to obtain the most net benefit from the funds budgeted.

After reference to an example listing of candidate projects (which will be discussed later in this paper),

the authors conclude: "The theoretically correct fiscal objective is the optimum improvement objective" (1, p. 9). This statement is not only puzzling; it is misleading. A false distinction is created that has no meaningful operational significance. For a given budget constraint, the agency's proper fiscal objective should be the maximization of net benefits from all investment opportunities. The optimum budget is that combination of investments—among sites, roadway designs, equipment, and so on—that maximizes net benefits. All subproblems at the design level can be accommodated under this rule.

BENEFIT/COST RATIOS

The NCHRP report discusses three methods for evaluating independent alternatives: (a) benefit/cost (B/C) ratio, (b) rate of return, and (c) payback period. Here, alternatives are independent if the selection of one alternative does not preclude the selection of any of the others.

The B/C ratio for a given project is defined in the usual way, as equal to either (a) the ratio of equivalent uniform annual benefits (EUAB) to equivalent uniform annual costs (EUAC), or (b) the ratio of the equivalent present worth of benefits (PWOB) to equivalent present worth of costs (PWOC). That is,

$$B/C = EUAB/EUAC = PWOB/PWOC \quad (1)$$

The authors then assert that the B/C ratios should be used to rank independent alternatives: "Order the improvements by magnitude of the B/C Ratios, largest to smallest" (1, p. 42). An example of the basic data for this procedure, as well as calculations of the B/C ratios, is given in Table 1.

The authors conclude that "the order by magnitude for these independent alternatives is B, D, A, C" (1, p. 42). That conclusion is strictly correct, but the inference is unjustified. It is true that

$$B/C(B) > B/C(D) > B/C(A) > B/C(C) \quad (2)$$

But it is not true that the economic preferences for these