The Use of High-Speed Vessels in Urban Ferry Service: Issues and Economic Evaluation

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The economic aspects of high-speed ferry operations are discussed and compared to conventional ferry services. The economic viability of high-speed service is demonstrated using conventional economic analysis techniques. Issues related to high-speed ferry operations such as safety, efficiency, and ridership attraction are discussed in more general terms. The paper concludes that high-speed ferry operations can compare favorably with conventional services and hold the potential for attracting larger numbers of passengers and charging premium fares.

In March 1979 the Transportation Training and Research Center of the Polytechnic Institute of New York began work on a series of studies related to the planning of urban ferry services. This work continued under contract to the Maritime Administration of the U.S. Department of Transportation until November 1981 (1,2).

In this paper the focus is on an issue that proved central to every facet of the project: the potential use of high-speed vessels in urban ferry service.

HIGH-SPEED TECHNOLOGY

A high-speed vessel is defined as any vessel that operates at speeds of 25 knots or greater. There are a variety of basic technologies that provide for such speeds. Some vessels producing speeds far in excess of this limit are hydrofoils, hovercraft, and high-speed catamarans.

There are two major benefits to the potential use of high-speed vessels:

1. The combination of straight-line, minimum distance connections over water with high-speed operation can shorten the travel time significantly compared with alternative land routes.
2. High-speed vessels can be used more efficiently than slower conventional vessels and usually require significantly smaller crews.

These benefits, however, must produce a service capable of attracting ridership and of operating economically. The following sections address the latter issue in some detail.

COST OF OPERATIONS

The costs of operating a ferry service include the terminal and vessel-related expenses. For purposes of comparing vessel economics, terminal costs were considered to be relatively constant although different vessel types may require different terminal design configurations. In general the vessel costs of interest include

1. Capital costs. The cost to buy the vessel, usually expressed as an equivalent annual cost amortized over the service life of the vessel at an appropriate interest rate (15 percent was assumed for these calculations).
2. Variable operating costs. The three major subcategories of operating cost that vary with vessel use are (a) crew costs, (b) fuel consumption, and (c) maintenance.

Table 1 gives the basic statistics for the different vessel types that are compared. All are models now in operation. For convenience only vessels that carry passengers are compared, and vehicle-carrying models are not included.

Capital Costs

The equivalent annual cost of a vessel may be computed from the following equation:

$$ACV = IC \times CRF(sl,i)$$

where

ACV = annual cost per vessel, dollars,
IC = initial cost of the vessel, dollars, and
CRF (sl,i) = capital recovery factor for the service life of the vessel (sl) at interest rate (i).

The results of this computation for the vessels shown in Table 1 are given below.

Vessel Code	Annual Cost of Vessel (1981 $)
A	910,860
B	1,741,820
C	2,716,600
D	2,165,800
E	204,204
F	753,389
G	495,040

Crew Costs

Complete details of the crew cost computations are not shown because of their complexity. The crew size for each vessel is given in Table 1, and the hourly crew cost per vessel is computed as

$$C = \sum_{i=1}^{n} N_i W_i$$

where

C = crew cost per vessel-hour,
N_i = number of crew members in category i,
W_i = hourly wage plus benefits for category i, and
n = number of labor categories included in the crew.

As the crew size required becomes smaller, the crew members tend to be in higher wage categories; thus, the average wage per crew member is higher for vessels with smaller crews. Crew costs per vessel-hour for the various vessels being compared are given below. Wage and benefit scales may vary significantly by location.

Vessel Code	Crew Cost per Vessel-Hour (1981 $)
A	60
B	144
C	245
D	71
E	35
F	61
G	80

Table 1. Vessels used in comparisons.

ID Code	Vessel Name	Vessel Type	Capital Cost ($)	Service Life (yr)	Crew Size	Operating Speed (mph)	Terminal Time (hr)	Fuel (gal/hr)	Maintenance Cost ($/hr)	Passenger Capacity
A	Vancouver SEABUS	Conventional	5,700,000	25	4	15.5	0.05	75	50	400
B	Golden Gate Ferry	Semi-planing	10,900,000	25	10	28.0	0.17	642	125	750
C	Staten Island Ferry	Conventional	17,000,000	25	15	16.0	0.15	300	69	5,700
D	Boeing Jetfoil	Hydrofoil	14,000,000	20	5	46.0	0.11	540	219	242
E	HM2-Mark III	Hovercraft (amphibious)	1,320,000	20	2	31.0	0.05	35	31	60
F	Bell Halter SES	Hovercraft	4,870,000	20	4	35.0	0.11	176	75	240
G	Westermaran	High-speed catamaran	3,200,000	20	5	29.0	0.07	540	75	175

Note: All prices based upon 1981 levels. All vessels carry passengers only.

Fuel Costs

Fuel consumption is one of the more controversial aspects of high-speed vessels. With the exception of the Bell-Halter SES, virtually all high-speed vessels have gas-turbine engines instead of the more conventional diesel engines. Although gas-turbine engines produce far more power per unit of engine weight, they also consume far more fuel, a significant economic factor.

The standard unit for vessel fuel consumption is gallons per vessel-hour of operation. For planning purposes, however, fuel consumption per passenger-mile is a more meaningful number. The conversion can be made as follows:

$$F_{PM} = F_{VH}/(CAP \times OS)$$

where

F_{PM} = fuel consumption per passenger-mile,
F_{VH} = fuel consumption per vessel-hour,
CAP = passenger capacity of the vessel, and
OS = operating speed of the vessel in mph.

This conversion assumes that vessels are 100 percent loaded and gives a passenger-mile fuel consumption rate based on full capacity. Table 2 gives the fuel consumption rates for the vessels studied.

In general higher-speed vessels will consume more fuel per hour and per passenger-mile than conventional vessels. Thus, high fuel costs must be considered to be a significant deterrent to the use of high-speed vessels.

Maintenance Costs

Maintenance costs vary with both the age and type of vessel and the quality of the maintenance standards of a particular system. Gas-turbine engines usually cost more to maintain than diesel engines; therefore maintenance costs are higher for most high-speed vessels as shown below.

Vessel Code	Maintenance Cost per Vessel-Hour (1981 $)
A	50
B	125
C	69
D	219
E	31
F	75
G	75

Total Variable Operating Cost

The estimated crew, fuel, and maintenance costs are combined in Table 3. Total variable operating costs are shown by cost per vessel-hour and cost per passenger-mile.

Note that on a passenger-mile basis conventional vessels have lower operating costs than their higher-speed counterparts. The high-speed catamaran is extremely costly because its hull remains submerged during operation and high speed is accomplished by overcoming friction and drag. The Boeing Jetfoil (vessel D), the fastest craft included, has the next highest operating costs.

The effect of speed on the cost comparison is most strikingly illustrated by vessels A and B: A is a conventional vessel used for the Vancouver SEABUS, and B is a semi-planing high-speed vessel used in San Francisco. Although vessel B has an operating cost per vessel-hour that is 4.9 times that of vessel A, its cost per passenger-mile is only 1.3 times that of vessel A because of its speed and larger passenger capacity.

Table 2. Fuel consumption rates.

Vessel Code	Gallons per Vessel-Hour	Gallons per Passenger-Mile
A	75	0.012
B	642	0.031
C	300	0.003
D	540	0.049
E	35	0.019
F	176	0.021
G	540	0.108

Note: 1981 vessel fuel averaged $1.00 per gallon. Thus, these figures also represent dollars.

Table 3. Total variable operating costs of vessels (1981 dollars).

Vessel Code	Vessel Type	Cost per Vessel-Hour	Rank[a]	Cost per Passenger-Mile	Rank
A	Conventional	187	6	0.03	6
B	Semi-planing	910	1	0.04	4-5
C	Conventional	614	4	0.01	7
D	Hydrofoil	830	2	0.08	2
E	Hovercraft	101	7	0.05	3
F	Hovercraft	312	5	0.04	4-5
G	High-speed catamaran	695	3	0.14	1

[a]From most costly to least costly.

Nevertheless, Table 3 clearly indicates that the cost of providing passenger service by high-speed vessels will be more than the cost by conventional vessels and that economic viability will depend on other factors to offset this cost.

ECONOMIC COMPARISONS OF HIGH-SPEED VESSELS

The critical factors that offset the higher cost of high-speed vessels are the number of vessels that must be used to provide service and the number of hours they must operate. With higher speeds, vessels make a trip in less time and can make more trips in a given schedule period. This translates into fewer vessels needed and fewer man-hours of labor needed to operate them.

The trade-offs are best illustrated by example. Consider that the service given below is to be initiated.

Route length =	2 miles one way
Operating schedule =	12 hours per day, weekdays only
Demand	
Peak hours =	2,000 passengers per hour for one-peak hour in each direction (2 hours), in peak direction of travel
Off-peak hours =	500 passengers per hour for 10 off-peak hours in peak direction of travel.

Vessels A, E, and G will be compared for this service.

Number of Vessels Needed

The number of vessels purchased will be the number needed to provide peak-hour service plus extra vessels to cover breakdowns. For the purposes of this analysis, one extra vessel will be assumed for each type of craft considered.

Critical to the number of vessels required is the total round-trip time. This establishes the time between repeat trips and includes the route travel time plus the time spent in each terminal. The round-trip time is computed as

$$T_i = (L/OS_i) + nt_i$$

where

T_i = round-trip travel time for vessel i,
L = round-trip length, miles,
OS_i = operating speed of vessel i, mph,
n = number of terminals at which vessel stops, and
t_i = terminal time, hours.

Thus, for the vessels under consideration

T_A = (4/15.5) + 2 (0.05) = 0.36 hour,
T_E = (4/31) + 2 (0.05) = 0.23 hour, and
T_G = (4/29) + 2 (0.07) = 0.28 hour.

The number of vessels needed in peak-hour operations depends on whether a vessel can make more than one trip in 1 hour. Where T_i is less than 1 hour, some vessels will make two or more trips during the peak hour.

Specifically the vessels will make the following number of trips in an hour:

N_A = 1/0.36 = 2.78 trips,
N_E = 1/0.23 = 4.35 trips, and
N_G = 1/0.28 = 3.57 trips.

Fractional values are acceptable because a vessel may make five trips in 2 hours, for an average of 2.5 trips per hour.

On the average, the number of passengers that can be processed during an hour is given by

$$P_i = N_i \times CAP_i$$

where

P_i = number of passengers per hour served by one vessel (type i),
N_i = number of trips per hour for vessel i, and
CAP_i = passenger capacity of vessel i;

and

P_A = 2.78 x 400 = 1112,
P_E = 4.35 x 60 = 261, and
P_G = 3.57 x 175 = 625.

The number of vessels to be purchased may now be expressed as

$$NV_i = (D_p/P_i) + 1$$

where

NV_i = number of vessels of type i needed,
D_p = peak-hour passenger demand in peak direction,
P_i = number passengers per hour serviced by vessel i, and
1 = one extra vessel;

and

NV_A = (2000/1112) + 1 = 2.8 (or 3),
NV_E = (2000/261) + 1 = 8.7 (or 9), and
NV_G = (2000/626) + 1 = 4.2 (or 4).

Vessel-Hours of Operation

During peak periods vessels may be expected to be fully loaded, and the number of round trips made during the two daily peak hours may be expressed as

$$NTP_i = (D_p/CAP_i) \times 2 = 2D_p/CAP_i$$

where

NTP_i = number of round trips made by vessels of type i during peak hours;

and

NTP_A = (2000x2)/400 = 10,
NTP_S = (2000x2)/60 = 67, and
NTP_G = (2000x2)/240 = 17.

During off-peak periods vessels will not be fully loaded. A load factor of 0.60 is assumed for this study, and the number of round trips made during off-peak periods is expressed as

$$NTO_i = (D_o/0.6\ CAP_i) \times 10 = 10D_o/0.6\ CAP_i = 16.7(D_o/CAP_i)$$

where

NTO_i = number of round trips made by vessels of type i during off-peak hours, and
D_o = demand per hour during off-peak hours;

and

NTO_A = 16.7 (500/400) = 21,
NTO_E = 16.7 (500/60) = 139, and
NTO_G = 16.7 (500/240) = 35.

The number of annual vessel-hours of operation is then found by

$$AVH_i = (NTP_i + NTO_i) \times T_i \times 260$$

where

AVH_i = annual vessel-hours of operation (vessel type i);
NTP_i, NTO_i, and T_i are as previously defined; and
260 = number of weekday per year;

and

AVH_A = (10+21) (0.36) (260) = 2,901.6,
AVH_E = (67+139) (0.23) (260) = 12,318.8, and
AVH_G = (17+35) (0.28) (260) = 3,785.6.

Final Comparisons

The total annual cost of operating the service with the three vessel types is given by

$$AOC_i = (NV_i \times AC_i) + (AVH_i \times CVH_i)$$

where

AOC_i = total annual operating cost for vessel type i,
NV_i = number of vessels purchased of type i,
AC_i = annual cost of amortizing vessel type i,
AVH_i = annual vehicle-hours for vessel type i,
CVH_i = cost per vessel-hour for vessel type i (Table 3);

and

AOC_A = (3x910,860) + (2901.6x187) = \$3,275,179,
AOC_E = (9x204,204) + (12,318.8x101) = \$3,082,034, and
AOC_G = (4x495,040) + (3,785.6x695) = \$4,611,152.

Although the final comparison is close, vessel E, a high-speed hovercraft, is the most economic choice--despite its high operating cost per passenger-mile and low capacity. Although more vessels are needed, their lower initial cost and the increase in the number of trips per hour more than make up for higher operating costs.

Additional Factors

The previous analysis has demonstrated that the economics of high-speed vessels in urban ferry use can be favorable. The analysis, however, is based on a constant passenger demand. This ignores the potential impact of high-speed vessels on ridership.

Countless studies of modal split behavior have indicated that travel time is a major factor in mode selection. It is reasonable to assume that the use of high-speed vessels as opposed to conventional vessels could attract larger numbers of passengers. This can result in higher load factors or in the need for more service.

Additional work is now being performed that will link a demand forecasting model to an economic analysis such as this one to assess an economically optimized service.

CONCLUSIONS

The principal conclusion of this study is that high-speed ferry services can be feasible. The high costs of high-speed vessel operation do not automatically dictate that conventional ferry services are more economical.

Waterborne options, particularly those involving high-speed vessel technology, warrant careful consideration where they exist. This paper has primarily treated vessel costs and economics, but the costs for water terminals are, in many cases, much less than the cost of fixed facilities required for land-based modal alternatives.

Lastly, modern high-speed vessels have a potential for attracting riders that has not been fully assessed in this country. The widespread use of these vessels throughout the world suggests that there is a role for them in the United States as well.

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