High-Speed Passenger Ferry Service: A Case Study

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This case study evaluates the introduction of a high-speed passenger ferry to replace or compete with the existing Staten Island Ferry. The analysis compares three types of high-speed vessels, discusses the technology, general characteristics, operating conditions, and cost, fare structure, and passenger shifts. The analysis determines that 10 new 1,500-passenger, high-speed, surface-effect ship-type vessels operating at 35 mi/hr would be required to replace the existing ferry. This new system would attract 25 million passengers annually, which would be an increase of 20 percent over existing conditions. The results of this research are very encouraging, pointing to the exciting prospect of introducing high-speed ferry service.

To make high-performance passenger ferries competitive with land alternatives, engineers have sought to overcome the barriers that water imposes by reducing surface drag and improving ride quality by removing the vessel from the motions and actions of tides, waves, and currents. The solution to this problem has been use of the hovercraft, the hydrofoil, and the catamaran.

The hydrofoil rides on the hydrodynamic lift created between the upper and lower surfaces of its underwater foil as it moves through the water; whereas the hovercraft lifts itself from the water by either a dynamic or a static cushion of air and the catamaran uses a dual-hull design for minimum resistance to forward motion. These types of vessel are used in regular passenger service in 52 countries around the world. Since the 1964 New York World's Fair, there have been many high-speed demonstration projects which have resulted in only a few new services in the United States.

TECHNOLOGY

The hydrofoil operates above the surface of the water, supported by underwater foils connected to the vessel hull. At optimum speed, the foil generates the dynamic lift necessary to fully support the vessel's weight, placing the hull on top of the water. This permits the vessel to operate at higher speeds. Two basic types are the surface-piercing foils, which operate with only the area necessary to support the vessel at any given speed submerged, and the fully submerged foil, which operates entirely below the water surface.

The Jetfoil is a fully submerged foil type of vessel that has practically no wake, even while maneuvering. The vessel's speed ranges from 45 to 50 knots in seas of up to 16 ft. To date, the comfort characteristics of the vessel are better than any other and it has been described as the 747 of waterborne transportation.

The surface-piercing vessel is limited in its operation because of its wide fixed foil structure. It is capable of speeds of 30 to 40 knots, but in rough seas the ride quality is not quite equal to the Jetfoil.

The hydrofoil is uneconomical, operating below its design speed, because of high-vessel drag. The Jetfoil has the capability of retracting its foil; the surface-piercing foil does not, which presents operational problems in shallow water requiring deep berths and channels for hull-borne operation. The surface-piercing vessel does not serve as a boarding platform and cannot be brought alongside another structure or object without the risk of damage. The maneuverability of the surface-piercing foil is not quite as good as the fully submerged type because of the foil strut limitations. Whenever floating and subsurface debris is present, foil vulnerability can be a significant operating problem.

The hovercraft is supported above the surface of the water by a cushion of air and is classified into two basic categories: the air cushion vehicle (ACV) and the surface-effect ship (SES).

The ACV has a flexible skirt enclosing the air cushion, giving it the capability of operating over both land and water. These vessels are almost totally free of the water surface and propulsion is achieved by aircraft-type variable pitch propellers. ACVs have operated in calm waters at speeds of up to 75 mph. The ACV's principal disadvantages are (a) the speed declines with increases in sea state; (b) they are not as seaworthy as other high-performance vessels, being susceptible to wind drift; (c) significant spray in a stopped or slow-speed operation is created; and (d) the ride quality at high speed is not particularly comfortable.

The SES has rigid sidewalls that penetrate the water surface and extend the length of the vessel, joined fore and aft by flexible skirts that extend beneath the surface of the water to contain the air cushion. Unlike the ACV, the SES uses conventional marine propulsion and control technology. The design of the SES provides greater stability and a more effective air-cushion containment than that of the ACV. When operating on cushion, the sidewalls remain immersed and the hull bottom is elevated several feet. SESs are not amphibious; they are supported by an air cushion as well as by a hydrostatic and hydrodynamic lift on the sidewalls. The rigid sidewall gives the vessel directional stability, and the use of the conventional propulsion and control system increases the vessel's maneuvering capabilities. The SES is more efficient than the ACV at the same speed. Because of the hull design, the lift

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power requirements are reduced, allowing the efficient use of the propulsion system.

The catamaran's hull is C-shaped. Its most important features are the high degree of stability, excellent maneuverability, and capability of medium-to-high speed without sophisticated equipment. The ride quality is not equal to that of the hydrofoil. The catamaran is designed for least resistance to forward motion and is thus capable of speed with comfort.

Passenger Comfort

Ride comfort is a complex subject and depends to a great extent on the movement, acceleration, and frequency in the 6 degrees of freedom of movement (roll, pitch, heave, yaw, sway, and surge). The movement of the vessel and the levels of acceleration are dependent on sea state and the vessel's response, in addition to the its heading, speed, and the direction of the sea. Experts have tried to quantify ride comfort and establish evaluation criteria, but this effort has been less than satisfactory. They do agree, however, that a high level of comfort is essential to a successful operation.

Wake Characteristics

The wake created by high-performance vessels in normal operation is less than that of a conventional displacement vessel. The ACV generates a large stern wave while reaching optimum operating speed. At optimum speed, there are no significant wakes. Because a portion of the hull remains in the water, the SES does experience a slight bow and stern wave. The hydrofoil generates practically no wake because of the extremely low volume of water displaced while it is foilborne. The catamaran, because it displaces more water than other high-performance vessels, generates a wake less than that of conventional vessels.

A HIGH-SPEED FERRY FOR STATEN ISLAND

The ferry is the primary transportation link between Staten Island and the Manhattan central business district (CBD), with terminals located in St. George (Staten Island) and Whitehall (Manhattan). This service has existed since the early 17th century and today carries 21,000,000 passengers a year. It operates 7 days a week, 365 days a year, around the clock, with a seven-vessel fleet with capacities ranging from 1,200 (Austin Class), 3,500 (Kennedy Class), to 6,000 (Barberi Class) passengers. The total trip distance is 5 mi, trip time is 30 min, and round-trip fare is 25 cents. The vessels operate at an average speed of 15 mph. Scheduling allows for 15-min rush-hour headways, 20- to 30-min midday headways, and 1 hr in late evening. Time is allocated for fueling, cleaning, preventive maintenance, emergency downtime, and required dry docking and inspection.

TABLE 1 BASIC SYSTEM INFORMATION

	VESSEL TYPE					
ITEM	KENNEDY	BARBERI	SES(1)	SES(2)	JETFOIL	FORMULATION
INITIAL CPTL COST ($1M)	7.0	16.0	9.0	12.0	18.0	IC
ANNUAL COST ($1M)	1.1	2.5	1.4	1.9	2.9	AVCC=ICxCRF
SERVICE LIFE (YEARS)	25	25	20	20	20	SL
PASSENGER CAPACITY (000)	3.5	6.0	.65	1.5	.4	CAPi
CREW SIZE	13	15	5	7	5	CS
TRIP LENGTH (ROUND-TRIP)	10	10	10	10	10	L
OPERATING SPEED (MPH)	15	15	35	35	45	OSi
NUMBER OF TERMINALS	2	2	2	2	2	NT
TERMINAL TIME (HR)	.16	.16	.13	.15	.13	TEi
TRAVEL TIME RT (HR)	1.0	1.0	.55	.60	.50	Ti(*)
ROUND-TRIPS (HR)	1.0	1.0	1.82	1.66	2.00	Ni=1/Ti
# PK-HR PASS/VESSEL (000)	3.5	6.0	1.18	2.49	.80	Pi=NixCAPi
TOTAL TRIP TIME (HR)	.50	.50	.27	.30	.25	Ti/2
FUEL CONSUMPTION (GAL/HR)	200	220	300	450	540	Fi
FUEL(GALS/PASS-MILE)	.001	.002	.013	.009	.013	FGPM
VARIABLE COST (PER HOUR OF OPERATION)						
FUEL COST ($)	200	220	300	450	540	FC
MAINTENANCE COST ($)	75	75	75	125	220	MC
CREW COST ($)	320	370	100	135	100	CC = $\sum_{i=1}^{n} N_i W_i$
TOTAL VARIABLE COST ($)	595	665	475	710	760	TVC

RT - round-trip
PK-HR - peak-hour
CRF - capital recovery factor for the service life at 15% interest
Ni - number of crew members in work category i
n - number of labor classifications included in the crew
Wi - hourly wages plus benefits for work category i

FUEL (GAL/PASS-MILE) = Fi/ CAPi x OSi
* Ti = L/OSi + NT(TEi)

ANALYSIS

This analysis is limited to vessel operating costs (cost of terminal facilities is assumed to be constant) including vessel construction costs amortized over the vessel's service life (15 percent interest rate based on the financial risk of the proposal) and variable costs (crewing, fuel, and maintenance). The basic system information for the existing ferry, Bell-Halter SES and Boeing Jetfoil is presented in Table 1.

From earlier research conducted by the author on waterborne transportation user characteristics, it was determined that reducing the Staten Island Ferry travel time, by increasing operating speed, resulted in significant increases in ferry ridership. By reducing ferry travel time, the impact of introducing a high-speed ferry was evaluated. It was found that by reducing the model's ferry travel time by 50 percent, 35 percent more users were attracted from the competing modes. (*1*).

Docking for the SES and Jetfoil requires stopping, turning around, and backing in. Loading and unloading is at the ground level, whereas the conventional ferry has a double-ended configuration, with loading and unloading at two levels.

Total Cost

On a cost-per-vessel-hour basis, the SES(1) vessel has the lowest variable operating cost. It can be seen from Table 1 that, except for the SES(1), high-performance vessels will cost more than conventional types and their economic viability will depend on other mitigating factors necessary to offset this higher cost, such as the number of vessels used, hours of operation, and level and quality of service.

Vessel Requirements

The number of vessels required to replace the Staten Island Ferry depends on the service provided and the round-trip travel time during the peak hour. In Table 1, the round-trip travel time, the total number of round trips per hour and the number of passengers that can be processed during an operating hour are shown.

As previously discussed, if high-speed vessels are assigned to replace the conventional ferries with no fare increase, the projected increase in users is 35 percent (*1*). The Staten Island Ferry System transports approximately 13,500 passengers during the peak hour. The number of vessels that would be required for a new high-speed service are presented in Table 2.

Vessel Hours of Operation

The three Kennedy Class (3,500 passenger) vessels operate approximately 10,060 hr/yr, and the two Barberi Class (6,000 passenger) vessels operate for 6,250 hr/yr. During the peak hours, for the purpose of this analysis, high-speed vessels are considered to be 80 percent loaded. The number of round trips operating during the off-peak period will be 50 percent of the rush-hour total. The number of annual vessel hours of operation is found by using Equation 1, and the results are presented in Table 3.

$$
\begin{aligned}
AVHi = {} & (NVi \times TPHi) + [(NMDVi \times (16 - TPHi)] \times 255 \\
& + (NMDVi \times 16) \times 110 + (NFVi \times 8) \times 365 \\
& - [(NVi - 1) \times TSi] \times 255 \text{ (no. of operating weekdays)} \\
& - (NMDVi \times TSi) \times 110 \text{ (no. of weekend days and holidays)} \\
& - (NFVi \times TSi) \times 365 \text{ (days/yr)}
\end{aligned} \tag{1}
$$

where

- i = vessel type,
- $AVHi$ = annual vessel hours of operation,
- NVi = number of vessels in weekday peak-hour daytime service,
- $NMDVi$ = number of vessels in weekday, nonpeak-hour daytime service,
- $TPHi$ = number of peak hours' operating time,
- $NFVi$ = number of vessels in late night operation, and
- TSi = vessel preparation time.

Total Annual Operating Cost

The total annual cost of operating the service with the conventional and high-speed vessel is computed using Formula 2. The results are presented in Table 3.

TABLE 2 OPERATING INFORMATION

ITEM	KENNEDY	BARBERI	SES(1)	SES(2)	JETFOIL	FORMULATION
			VESSEL TYPE			
PK-HR PASS DEMAND (000)	13.5	13.5				DPi
ADD'L USERS HIGH-SPEED			1.35	1.35	1.39	HSFi
LOAD ADJUSTMENT FACTOR			1.20	1.20	1.20	LAFi
NO. VESSELS TYPE i	2	2	17	9	28	NVi(*)
TOTAL ADJUSTED PK-HR PASS LOAD (000)			21.87	21.87	22.52	TPCi
NO. ROUND-TRIPS PK-HR			37	18	56	NTPi=TPCi/Pi/2

* NVi = DPi x HSFi x LAFi/Pi

TABLE 3 ANNUAL VESSEL-HOUR OF OPERATION AND COST

ITEM	KENNEDY	BARBERI	VESSEL SES(1)	SES(2)	JETFOIL
NVi	2	2	19	9	28
NMDVi	2		2	1	3
TPHi	6		6	6	6
NFVi	1		1	1	1
TSi	1		1	1	1
AVHi	10,060	6,250	36,455	23,705	54,940
NVi+1	3	2	20	10	29
ACi	1.08	2.48	1.44	1.92	2.88
CVHi	595	665	475	710	760
AOCi($1M)	9.63	9.49	47.78	35.91	132.69
SYSTEM COST, NO AMORTIZATION($000)	29.27		50.87	39.42	131.78
AMORTIZATION($000)	8.20		28.80	19.20	83.52
TOTAL SYSTEM COST + AMORTIZATION($000)	37.47		79.67	58.62	215.30

$$AOCi = (NVi + 1) \times ACi + (AVHi \times CVHi) \qquad (2)$$

where

$AOCi$ = total annual operating cost for vessel, Type i,
$NVi + 1$ = number of vessels required, (includes one backup),
ACi = annual cost of amortizing vessel (millions of $),
$AVHi$ = annual vessel hours of operation, and
$CVHi$ = cost/vessel hour.

System Cost

The total annual operating cost does not include support personnel, administrative staff, materials and supplies, miscellaneous expenses, terminal costs, indirect expenses, and nonoperational fuel expenses. To adjust the total annual operating cost to reflect system cost, the system expense ratio (SER) is applied. The SER is obtained by dividing system cost by its annual operating cost. This cost does not include amortization of vessel capital investment. The Staten Island Ferry's total system cost is $29,270,000 and the total annual operating cost is $10,920,000, resulting in a 2.68 SER.

FINAL COMPARISON

By analyzing the total system operating cost and the total ferry users, the SES (1,500 passenger) is the most cost-effective vessel. Based on this result and the author's research on revenue and expenses versus users, an analysis was conducted to determine the break-even fare and its impact on ferry users (Table 4).

The break-even, one-way fare for the high-speed ferry is $2.37. This is based on a total system operating cost of $58,600,000 and a ridership of 25,300,000. The impact of varying both the travel time and the trip cost reflects the trade-off between reduced time and increased cost, indicating the importance of time in terms of the fares. This high fare would result in a 12 percent decline in potential ferry users at the existing fare (*1*). However, a $2.25 fare increase is not considered politically viable on Staten Island. Currently, ferry riders are charged only 12.5 cents for a one-way ferry trip. Local leaders, who continually advocate low ferry fares, might find a 19-fold increase hard to accept. The 20 percent increase in ferry users from the high-speed ferry, however, can have a significant impact on CBD traffic congestion and air quality.

A second analysis was conducted excluding the vessel capital cost from the calculations. The lowest system cost is $39.42 million for operating the SES(2), as indicated in Table 3. By instituting a break-even fare for the system, the total number of high-speed ferry users will equal 26.5 million passengers, requiring a one-way, break-even fare of approximately $1.50. This fare is competitive with the $4.00 express bus and automobile alternative but not with the fare being charged conventional ferry users. Using a $29.27 million total system operating expense (excluding the vessel capital cost), the

TABLE 4 EFFECTS OF SPEED AND COST ON FERRY RIDERSHIP (*2*)

FERRY FARE ONE-WAY (CENTS)	CHANGE IN FERRY RIDERSHIP CONVENTIONAL REVENUE	CONVENTIONAL USERS	THIRTY-FIVE MPH REVENUE	THIRTY-FIVE MPH USERS
12.5	2.6	21.0	3.6	28.4
50	10.0	20.5	14.0	27.9
100	20.0	19.5	27.4	27.4
160	30.0	18.5	42.3	26.5
230	40.0	17.5	58.9	25.6

SOURCE: Berkowitz, C.M., "Modeling Waterborne Passenger Transportation User Characteristics," Polytechnic Institute of New York, January, 1985 conventional ferry fare would have to be increased to approximately $1.40 one-way break-even. This fare level will result in the loss of approximately 2,000,000 users and a cost that is 10 cents lower than the cost of the proposed high-speed replacement service.

CONCLUSION

The results of this research are very encouraging, pointing to the exciting prospect of introducing a competitive high-speed ferry service between Staten Island and the Manhattan CBD.

REFERENCES

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