Using Big Data to Determine New Vessel Design Speed

Author name(s): Kurtis A. Jankowski[1] (AM)
1. Elliott Bay Design Group, Seattle, Washington, USA

Passenger ferry design speeds are often specified to meet sailing schedule requirements. Passenger loading times will increase with passenger ridership over the life of the vessel requiring greater transit speeds to maintain schedule. Transit speed and loading time for existing vessels can be used to more accurately determine the required increase in speed for future operations. In this paper, GPS output from the M/V ANDREW J BARBERI is used to evaluate the vessel's average transit speed, the average acceleration when approaching and departing each terminal, and the average passenger loading time. A model of the operating profile is developed from these statistics. Using estimates of passenger loading time from future ridership projections, the design speed required to maintain a normal operating schedule is calculated for the new 4500 Class Ferry for New York City Department of Transportation, Staten Island Ferry Division.

KEY WORDS: design speed; ferry; GPS

NOMENCLATURE

GPS	Global Positioning System
MCR	Maximum Continuous Rating
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration

INTRODUCTION

Ships are long term assets that must be capable of meeting service requirements for many years. Ferry vessels in particular need to maintain regular sailing schedules throughout their service lives, and as ferry ridership increases it is critical that these schedules are maintained. However, as ridership increases, so too will the time spent loading and unloading at the terminals. Therefore, a vessel's cruising speed must increase over time in order to maintain on-time operations throughout the vessel's service life.

The design speed required for a new vessel can be calculated from the operation of existing vessels in the fleet. GPS data provides a reliable source for a vessel's operational statistics such as speed and loading time. In this paper, GPS data is used to develop a model of the operating profile for an existing vessel in the New York City Department of Transportation, Staten Island Ferry Division fleet. This model is used to determine the design speed required for the new 4500 Class Ferry to meet the service requirements anticipated over the next 40 years.

PROCEDURE

GPS output collected on the M/V ANDREW J BARBERI between May and August 2011 was analyzed [1]. The M/V ANDREW J BARBERI is driven by Voith Schneider propellers and therefore has an operating profile comparable to the 4500 Class Ferry.

The GPS output was in NMEA format. This format outputs lines of NMEA "sentences" (shown below) in which the first "word" is the NMEA data type. The information following the data type is separated by commas and set by the NMEA standard.

```
$GPRMC,140924,A,4041.06,N,07402.12,W,
014.8,218.,030511,,*30
```

For this analysis, only the Recommended Minimum GPS sentence "`$GPRMC`" was needed. The data which follows the "`$GPRMC`" data type is: time, status, latitude, latitude hemisphere, longitude, longitude hemisphere, speed over ground, track angle, date, magnetic variation, and checksum data.

The NMEA data were analyzed with scripts written in version 3.4 of the Python programming language. The size of the data set was first reduced by extracting only the information required for the analysis, that being speed over ground, latitude, date, and time. All other data were removed to reduce the time and computer resources required to process such a large data set. The data were then cleaned by removing any NMEA sentences which contained non-numeric characters or incomplete sentences. After cleaning, the data contained 6.64E6 lines of GPS output and comprised a total of 1,325 one-way trips.

Initially, speed over ground was plotted against latitude in order to observe the overall route profile. This is shown in Figure 1. Three segments were identified from the overall operating profile: the transit region, Staten Island maneuvering region, and Manhattan maneuvering region. While not visible in the operating profile in Figure 1, a fourth segment of the route, terminal loading and unloading, was also identified. The data from each of these segments were used to complete a transit speed analysis, a maneuvering analysis, and a passenger loading analysis. Each of these analyses are discussed in detail in the following sections of this paper. The results of these analyses were used to develop a model of the route.

Estimates of future ridership were used to determine the increase in loading time, and the route model was modified to calculate the design speed required to maintain a 30 minute one-way trip.

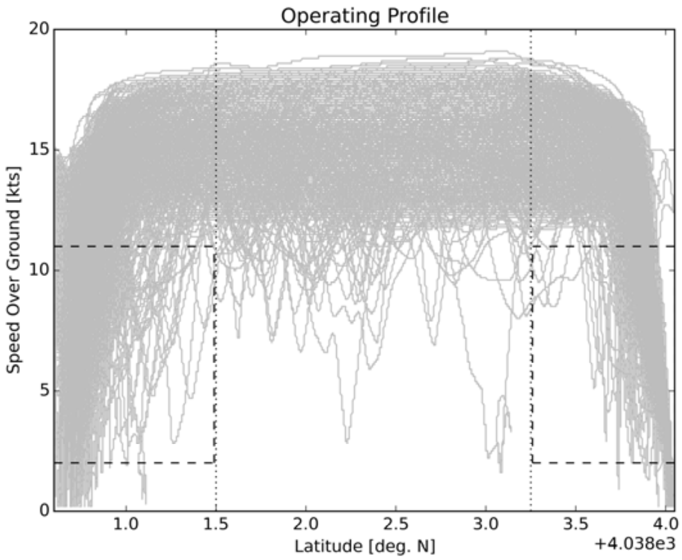

Fig. 1: The operating profile of the M/V ANDREW J BARBERI from all available data is shown in gray. The transit speed segment is indicated by two dotted black lines and the maneuvering segments are indicated by dashed black lines.

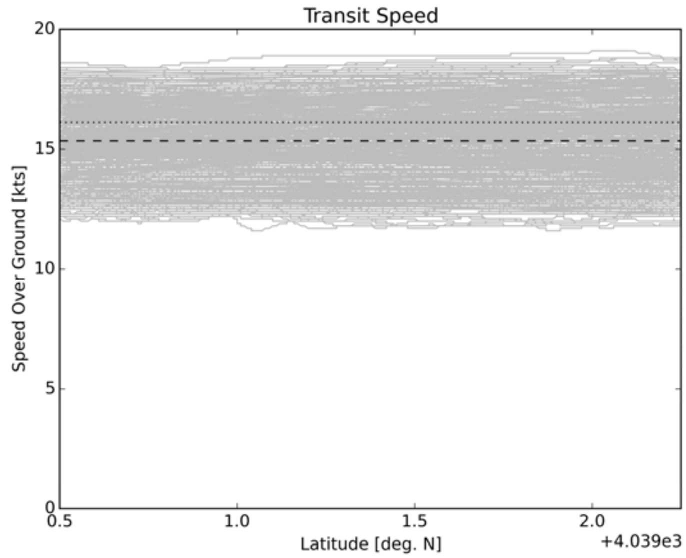

Fig. 2: The transit speed segment of the route filtered to remove periods of significantly reduced speed. The mean speed over ground is indicated by a dashed black line and the mean plus one standard deviation is indicated by a black dotted line.

Transit Speed Analysis

To evaluate the average transit speed, the data were filtered to include only those datum between 40º 39.50' N and 40º 40.25' N. These latitude limits were selected to encompass the period of constant speed during the middle of the route based on examination of the entire operating profile. A number of transits included periods of significantly reduced speed. These instances did not represent a typical transit scenario, so to prevent reducing the calculated steady state transit speed, any transit periods during which the difference between the maximum and minimum speed was greater than one knot were removed from the data set. This criterion resulted in 276 one-way trips being removed from the data and a transit speed over ground segment as shown in Figure 2.

The location of the route on New York Harbor's Upper Bay is subject to significant tidal and river currents. Therefore, the speed over water needed to be estimated from the speed over ground data provided by the GPS. To do this, historical current data [2] were obtained from NOAA for a location one mile west of Red Hook. This location, shown in Figure 3, was chosen for its proximity to the ferry route. It was assumed that, throughout the transit portion of the route, both the water current and the vessel were moving in the same (or opposite) direction. It was also assumed that the current was constant along the entire transit portion of the route.

The NOAA data gave only the points of still water and maximum current. Therefore, the current present at each transit speed datum had to be interpolated from these values. To do this, a fifth-order polynomial was fit through the five current datum surrounding each transit speed datum. The resulting interpolated current data are shown overlaid on the NOAA data

Fig. 3: The location of the tidal current data is shown in red. The approximate ferry route is indicated as a white line.

in Figure 4. With these values, the vessel's transit speed over water was able to be calculated.

Maneuvering Analysis

A maneuvering analysis was completed to calculate the typical acceleration from the terminal to full transit speed (and vice-versa). After examination of the overall operating profile in Figure 1, the maneuvering segments of the route were chosen to be from two to 11 knots and 40º 38.60' N to 40º 39.50' N and 40º 41.25' N to 40º 42.05' N for Manhattan and Staten Island, respectively. The acceleration in the maneuvering segments was calculated using the mode of the elapsed time between two and 11 knots.

No correction was made to the speed over ground data as it was assumed the current was negligible in the near shore maneuvering regions. It was also assumed that the acceleration

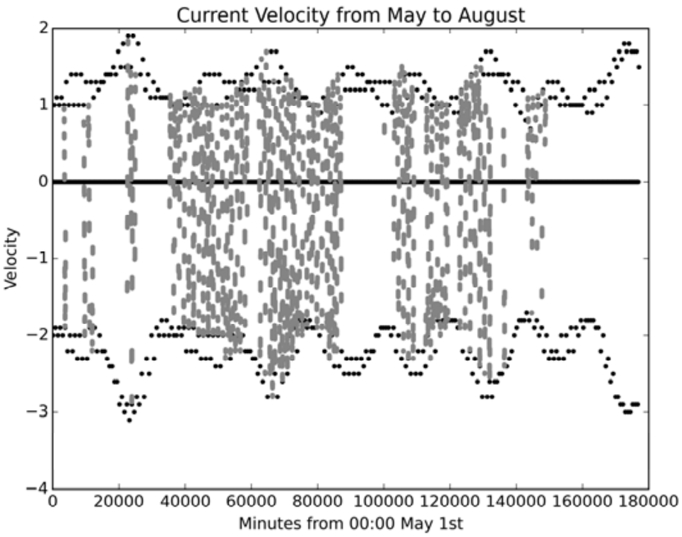

Fig. 4: The NOAA current data are shown in black. The interpolated current velocity at each speed over ground datum is shown in gray.

was constant from zero speed to full transit speed and that the vessel was following the 4.5 nautical mile route during the entirety of the maneuvering period.

Passenger Load Analysis

The average time spent loading and unloading passengers was determined with a passenger loading analysis. Loading times were considered to be the continuous periods spent at speeds less than 0.3 knots. Observed loading periods of less than 180 seconds were removed as it was assumed these were due to noise in the data.

RESULTS

The operating profile shown in Figure 1 is a composite of all speed over ground data plotted against latitude. The operating profile is typical of a Voith Schneider propelled vessel with rapid acceleration to and from a steady cruising speed.

Transit Speed Analysis

The distribution of speed over ground within the transit region is plotted in Figure 5. The mean speed over ground is 15.3 knots and the standard deviation is 1.5 knots. A normal probability density function has been overlaid.

The distribution of speeds is greatly spread and does not closely follow a normal distribution as would be expected from data such as this. This is due to the effect of the current on the vessel speed which is inadvertently captured in the speed over ground GPS data. Therefore, using speed over ground is not an accurate means of determining the true vessel transit speed. Instead, the vessel speed over water must be calculated by removing the current effects. As discussed, the currents were interpolated from NOAA data and used to calculate the vessel speed over water.

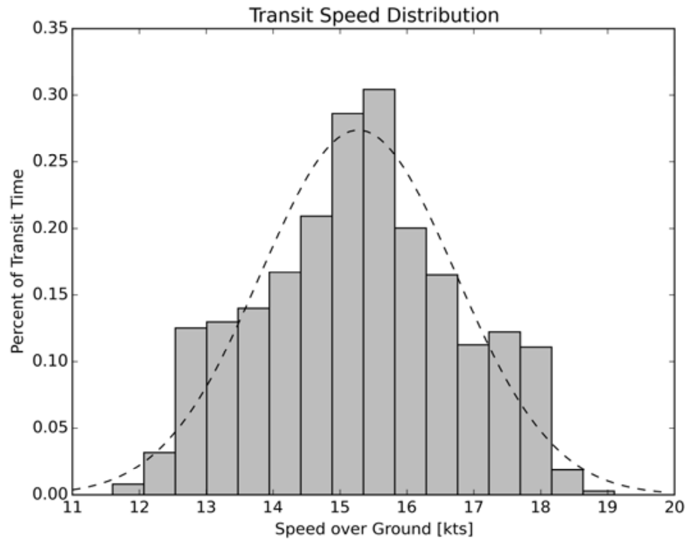

Fig. 5: The normalized histogram of speed over ground in the transit region is shown in gray. A normal probability density function has been overlaid in black. The mean speed over ground is 15.3 knots and the standard deviation is 1.5 knots.

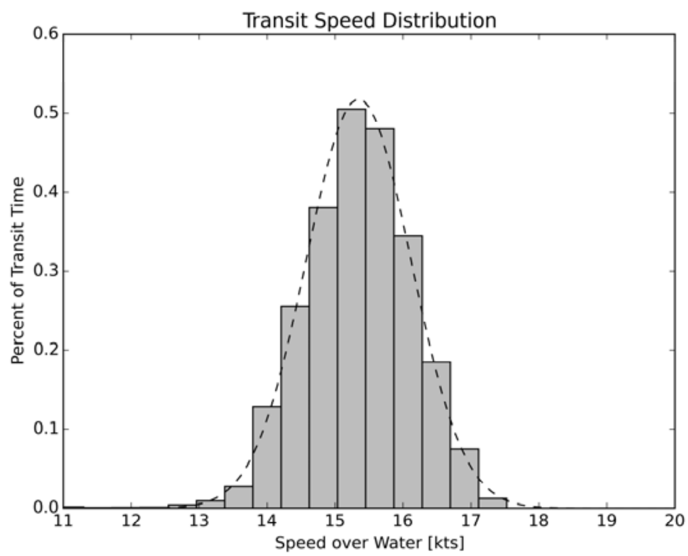

Fig. 6: The normalized histogram of speed over water in the transit region is shown in gray. A normal probability density function has been overlaid in black. The mean speed over water is 15.3 knots and the standard deviation is 0.8 knots.

The distribution of speed over water is shown in Figure 6 with a normal probability density function overlaid. The mean speed over water is 15.3 knots and the standard deviation is 0.8 knots. The spread of the speed over water data is much less than the speed over ground data. Furthermore, the data closely follows a normal distribution.

The 4500 Class Ferry design speed is based on the data presented above. Given that the transit speed follows a normal distribution, a speed which encompasses 84% of all observed transit speeds can be calculated as the mean plus one standard deviation. This results in a speed of 16.1 knots.

Maneuvering Analysis

Figures 6 through 9 show the time series of speed while approaching and departing the ferry terminals on Staten Island and Manhattan. In each plot, the data is shown in gray while the black line indicates the constant acceleration assumed in the operating model. As discussed, this rate is based on the mode of the time required to go from two to 11 knots.

Table 1: The acceleration during each maneuvering period.

Route Segment	Acceleration
Approaching Manhattan	-2.63 kts/min (-0.02 m/s^2)
Departing Manhattan	12.56 kts/min (0.11 m/s^2)
Approaching Staten Island	-4.35 kts/min (-0.04 m/s^2)
Departing Staten Island	5.93 kts/min (0.05 m/s^2)

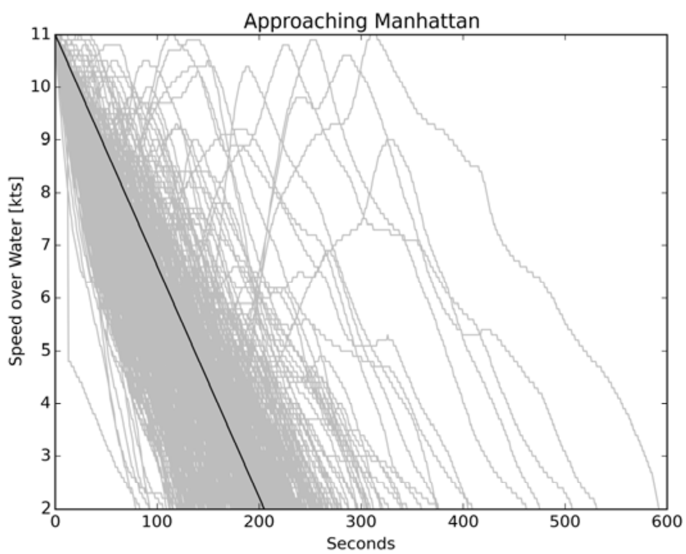

Fig. 6: The time series of speed when approaching the ferry terminal in Manhattan.

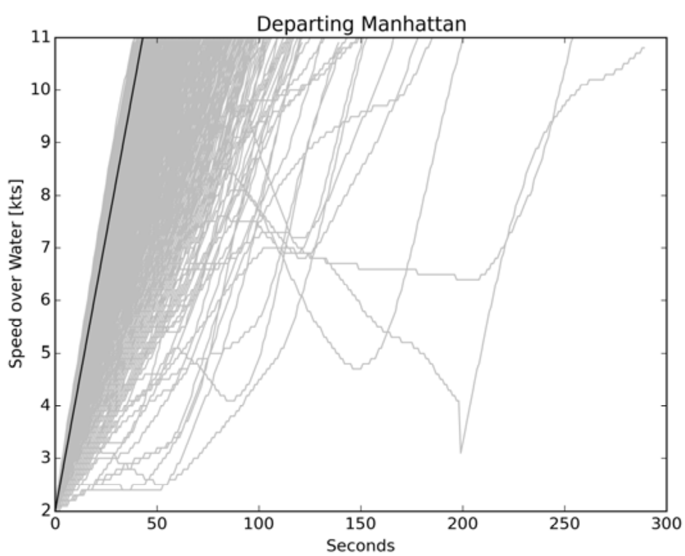

Fig. 7: The time series of speed when departing the ferry terminal in Manhattan.

It can be seen that the magnitude of acceleration is typically greater when departing the terminals than when approaching the terminals. This characteristic observed in the data was verified by Staten Island Ferry who explained that the ferries typically wait in the terminal until vessel traffic is clear. This accounts for the high acceleration when departing the Manhattan terminal where interfering marine traffic is easier to predict. The effect is less evident when departing the Staten Island terminal where vessel traffic is more difficult to predict until the ferry has departed the terminal.

The significant difference between the acceleration when departing Manhattan was considered suspect when first calculated, but was verified as reasonable by Staten Island ferry based on typical operating procedure.

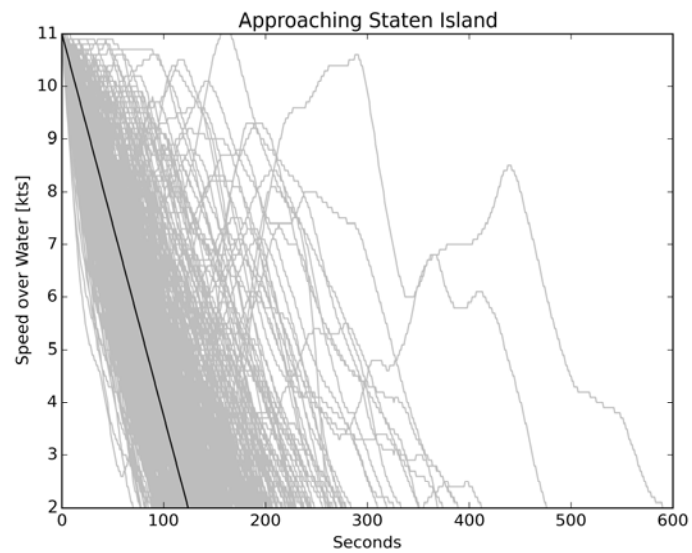

Fig. 8: The time series of speed when approaching the ferry terminal on Staten Island.

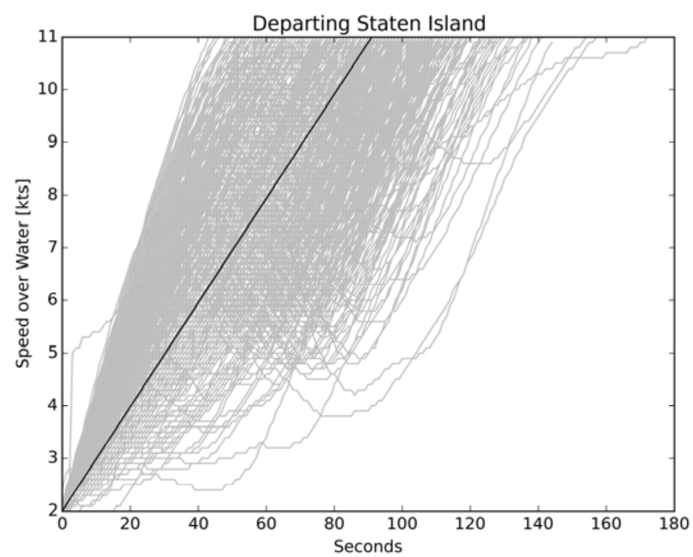

Fig. 9: The time series of speed when departing the ferry terminal on Staten Island.

Passenger Loading Analysis

The distribution of passenger loading and unloading time is shown in Figure 10. The typical loading period was observed to be 8.28 minutes. For this value, the mode of the data was taken so as not to skew the average with long periods of rest that do not reflect standard operations. For the purposes of the minimum speed analysis, it was assumed that equal time was spent loading and unloading passengers (i.e. that each loading or unloading period took 4.14 minutes).

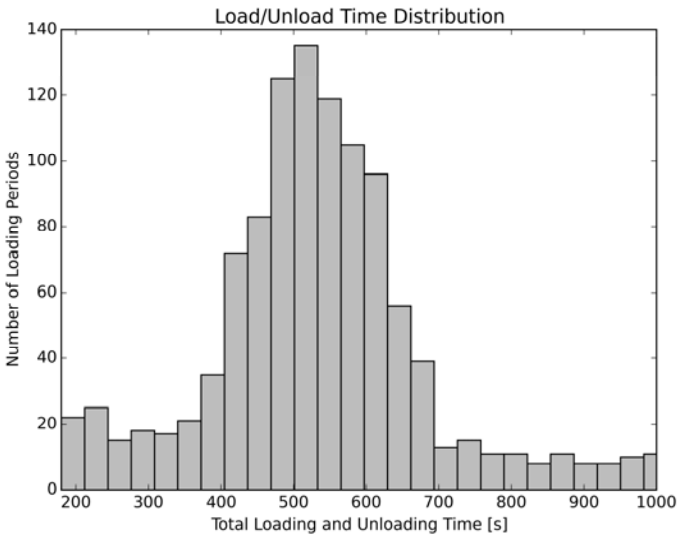

Fig. 10: The distribution of combined unloading and loading times at both terminals. The mode of the loading and unloading periods was 497 seconds or 8.28 minutes.

Minimum Speed

The acceleration rates calculated in the maneuvering analysis were used to calculate the time required to reach transit speed after leaving the terminal. With the loading and maneuvering times known, a simple model of the operating profile dependent on transit speed was developed. This is summarized in Table 2. The model was used to calculate transit speed in several scenarios.

First, the minimum transit speed required to complete a round trip in 60 minutes was calculated. The results of this calculation are shown in Table 2. The required minimum speed was found to be 14.5 knots. This figure is based on the current loading time of 8.28 minutes.

However, the primary driver of this study was to determine the design speed required for a new vessel to maintain the current sailing schedule during future periods of increased ridership. Based the operating profile it was determined that the limiting criterion was the ability to complete the Staten Island to Manhattan leg of the route in 30 minutes. This is because the significantly larger acceleration when departing the Manhattan terminal allows for lower transit speed while maintaining a 30 minute trip.

Table 2: The operating profile model of a round trip at the minimum transit speed.

Leg of Trip	Distance [nautical miles]	Time [minutes]	Average Speed [knots]
Loading in Staten Island	0.00	4.14	0.0
Departing Staten Island	0.29	2.42	7.3
Transit	3.54	14.65	14.5
Approaching Manhattan	0.66	5.48	7.3
Unloading in Manhattan	0.00	4.14	0.0
Loading in Manhattan	0.00	4.14	0.0
Departing Manhattan	0.14	1.16	7.3
Transit	3.95	16.33	14.5
Approaching Staten Island	0.41	3.39	7.3
Unloading in Staten Island	0.00	4.14	0.0
Total	**9.00**	**60.0**	
Transit Speed [knots]	**14.5**	« iterate to solve total time = 60	

Staten Island Ferry determined that a vessel would require a total of nine minutes for loading and unloading in order to accommodate future ridership levels. Based on this input, it was calculated that a transit speed of 16.3 would be required to maintain a regular schedule. A summary of the operating profile model in this condition is given in Table 3.

Table 3: The operating profile model of the limiting leg of the route at a 16.3 knot transit speed.

Leg of Trip	Distance [nautical miles]	Time [minutes]	Average Speed [knots]
Loading in Staten Island	0.00	4.50	0.0
Departing Staten Island	0.37	2.72	8.2
Transit	3.29	12.13	16.3
Approaching Manhattan	0.84	6.16	8.2
Unloading in Manhattan	0.00	4.50	0.0
Total	**4.50**	**30.00**	
Transit Speed [knots]	**16.3**	« iterate to solve total time = 30	

CONCLUSIONS

Based on the analysis detailed in this report, the recommended design speed of the 4500 Class Ferry was 16.3 knots. This speed encompassed 89% of the transit speeds observed on the M/V ANDREW J BARBERI from May through August of 2011 and allows the vessel to complete a round trip in 56.7 minutes without current, assuming the observed typical load/unload time of 8.28 minutes. This speed also allows the vessel to complete a trip from Staten Island to Manhattan with nine minutes of loading and unloading time. This design speed is critical to maintaining a regular operating schedule as the vessel ages and ridership increases.

Design Impacts

The calculated design speed of 16.3 knots had a significant impact on the design of the 4500 Class Ferry. The original design speed specified by the contract was 15.6 knots. Based on the final powering curve and assuming an engine rating of 85% MCR at cruising speed, a vessel designed to the specified contract speed would have had insufficient top speed to complete a trip from Staten Island to Manhattan in 30 minutes as passenger loading times increased. Multiple hullform and weight optimization efforts were undertaken to achieve the calculated design speed with shallow water effects. This indicates the importance of considering service requirements through the end of the desired service life during the initial design of the vessel.

ACKNOWLEDGEMENTS

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