JOHN W WATERHOUSE
STATE OF WASHINGTON
24294
REGISTERED
PROFESSIONAL ENGINEER
01/18/10

SOUTHEAST ALASKA TRANSPORTATION PLAN SHUTTLE FERRY STUDY

Final Report

Prepared for: Alaska Department of Transportation and Public Facilities • Juneau, Alaska

Ref: 09086-001-070-1 Rev. - **January 18, 2010**

Elliott Bay Design Group
Architectural & Engineering Services for the Marine Industry

PREPARED BY

Elliott Bay Design Group
5305 Shilshole Ave. NW, Ste. 100
Seattle, WA 98107

REVISIONS

REV	DESCRIPTION	DATE	APPROVED
–	Initial issue	01/18/10	JWW 24294

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In September of 2009, Elliott Bay Design Group (EBDG) was retained by the Alaska Department of Transportation and Public Facilities (ADOT/PF) to examine ferry vessels for Southeast Alaska. Specifically, the purpose of the study was to identify performance requirements and how they might impact the capital and operating costs of smaller ferries on minor routes. There were five tasks specifically identified: 1) Environmental Factors, 2) Route Analysis, 3) Study Vessels, 4) Vessel Cost Factors, and 5) Planning Factors. EBDG prepared four memorandums and two reports to address the five tasks and subsequent questions. Those documents have been incorporated into this final report.

For longer routes or those with exposure to higher sea states, vessel size may be dictated by an acceptable level of passenger comfort and hence reliability of service, instead of being dictated by traffic demand. The reliability of service and/or comfort standards are policy decisions by the operator.

Other factors influencing capital and operating costs include service speed, regulatory construction standards, inclusion of overnight accommodations, redundancy of systems, and terminal interfaces (loading ramps, mooring systems, waste management systems, etc.). To reduce costs, the vessel should be as simple as the mission will allow.

We looked at four known designs that have operated successfully in Alaska. They were evaluated based on capital cost, operating cost, and service reliability on existing and new routes in Southeast Alaska. We recommend the following vessel/route pairings if AMHS chooses a 99% service reliability standard.

Route	Length (nm)	99th Wave Height (ft)	Sea State	Recommended Vessel
200-300 miles				
Ketchikan-Petersburg	222	6.9	4.5	Aurora
Sitka-Juneau	264	7.1	4.6	Aurora
Juneau-Petersburg	246	6.3	4.2	Aurora
120-200 miles				
Prince Rupert-Ketchikan	190	5.6	3.8	IFA/Bartlett
Ketchikan-Wrangell	178	6.9	4.5	Aurora
Angoon-Juneau	156	7.1	4.6	Aurora
Sitka-Angoon	152	7.1	4.6	Aurora
Juneau-Hoonah-Gustavus	126	7.1	4.6	Aurora

Juneau-Haines	136	6.6	4.3	Aurora
Juneau-Haines-Skagway	162	6.6	4.3	Aurora
Under 120 miles				
Ketchikan-Hollis	80	5.5	3.8	IFA/Bartlett
Coffman Cove-Wrangell-South Mitkoff	92	6.9	4.5	Aurora
Wrangell-South Mitkoff	24	1.2	1.2	Lituya
Juneau-Hoonah	96	7.1	4.6	Aurora
Haines-Skagway	26	5.9	4	Lituya

TASK 1 – ENVIRONMENTAL FACTORS

In order to assist the Alaska Department of Transportation (ADOT) with future decisions regarding ferry design and route planning, we collected environmental data from a number of locations in Southeast Alaska. The locations were chosen to match the routes of interest to ADOT.

Procedure

The locations from which environmental data is desired are:

- Lynn Canal
- Icy Strait
- Chatham Strait
- Junction of Lynn Canal, Icy, and Chatham Straits
- Frederick Sound
- Stephens Passage
- Clarence Strait
- Revillagigedo Channel
- Dixon Entrance

The key environmental factors affecting ferry design and route planning are wind speed, wave height, and period. The sources of this information are National Data Buoy Center (NDBC) fixed land installations, National Weather Service (NWS) Alaska Region Stations, Canadian Government operated buoys, and other local weather stations.

The sources in the regions of interest do not contain wave data. The only such stations that take wave data are the NDBC moored buoys, and those are only present many miles out in the Gulf of Alaska. Because of this, methods must be employed to calculate the wave height based on wind speed, direction, fetch length, water depth, duration of wind, and other geographical features.

One widely used method for determining significant wave height based on the features stated above is the Army Corps of Engineers Shore Protection Manual (SPM) (Reference 2). These methods, however, were developed to predict waves in open water as opposed to the narrow straits and channels of Southeast Alaska. These methods also do not account for waves that have not yet become fully developed. It is verified using SPM methods that the waves are, in fact, not fully developed. The Vessel Suitability Study (VSS) (Reference 1) provides comparison for all locations except the Dixon Entrance, and the Southern Gateway Feasibility Study (Reference 3) provides comparison for the Dixon Entrance.

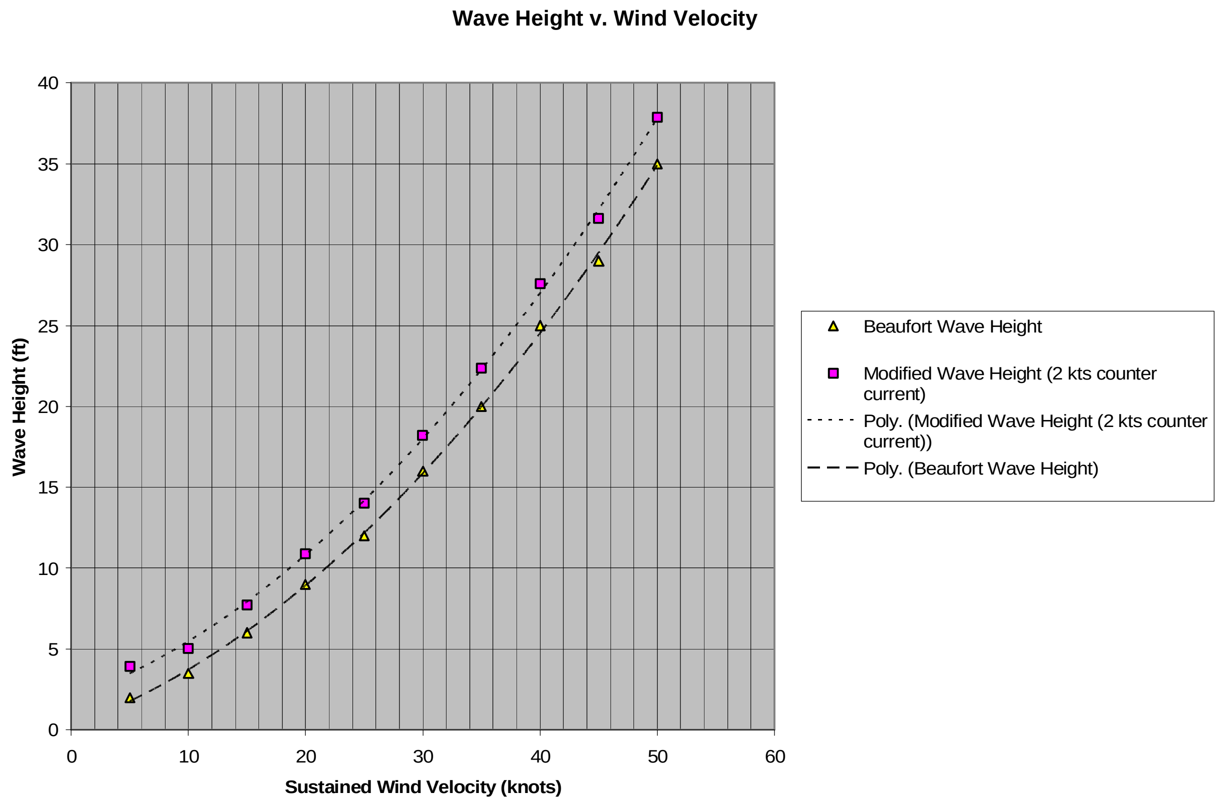
Results

The name of the weather station, where available, is given in parentheses below the location name. These weather stations can be located on the "Weather Station Data" chart in the "Charts" Section. The Reference 1 locations can be found in the "VSS Chart" of that section.

Location	95% Average Wind Speed (knots)	SPM Significant Wave Height (ft)	Ref 1 & 3 Sig. Wave Height (99% Average) (ft)
Lynn Canal (EROA2 & PRTA2)	35.1	11.8	6.6
Icy Straits (SISA2)	22.4	5.6	2.3
Chatham Straits	Not available	-----	6.8
Lynn/Icy/Chatham Junction	35.1	Not calculable	7.1
Frederick Sound (FFIA2)	27.3	7.2	4.6
Stephens Passage (FFIA2)	27.3	7.2	6.3
Clarence Strait (Annette Is.)	36.6	15.54	5.5
Revillagigedo Channel (Annette Is.)	36.6	15.54	5.6
Dixon Entrance (Reference 3)	Not available	-----	6.5 (95% average)

The SPM method over predicts the wave heights since it assumes fully developed waves. Because of this, the results from References 1 and 3 should be used where possible because they present the results of more detailed analyses that accounts for wind duration.

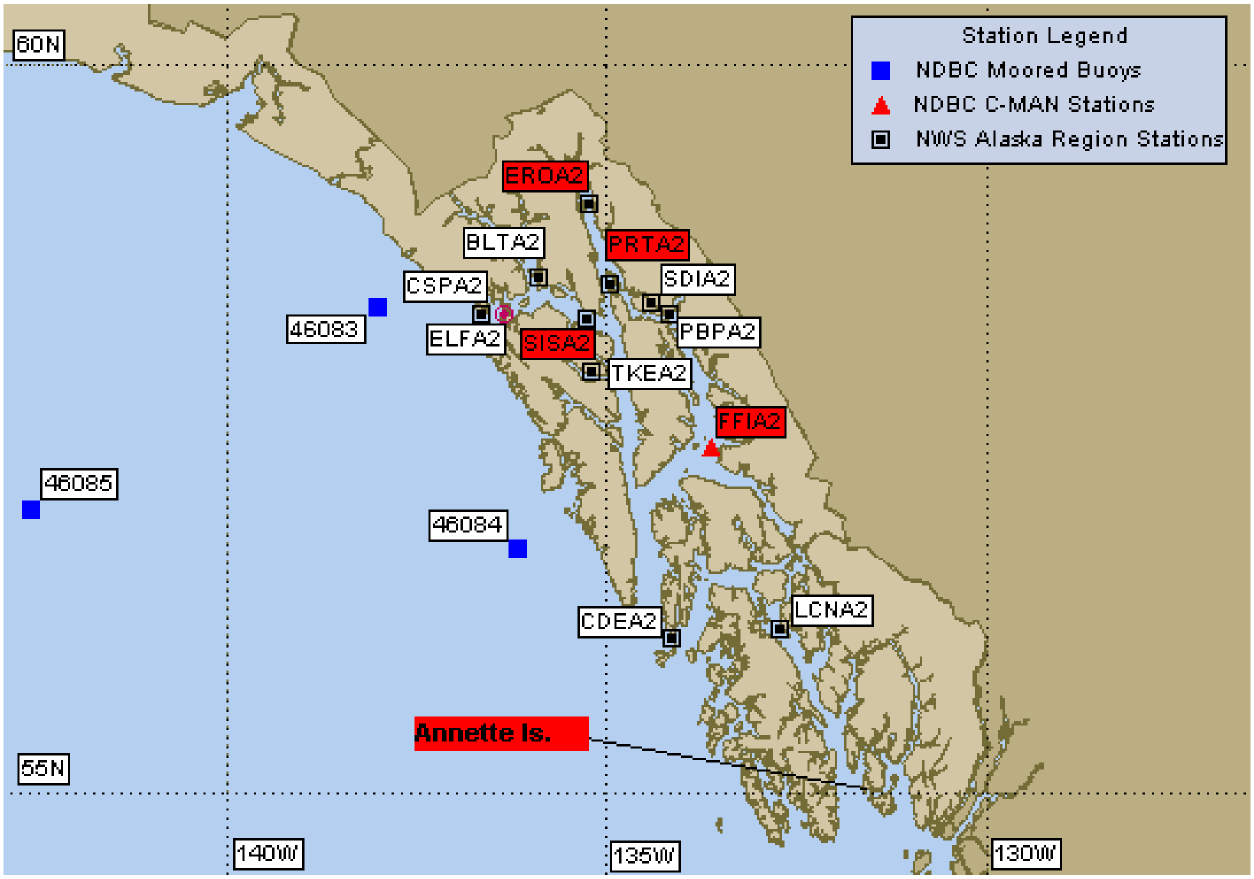
In some areas of southeast Alaska there are significant tidal currents which can affect wave heights. If we assume that the counter current acts as an effective increase in the wind velocity, we can estimate the effect on wave height. Below is a graph of fully developed wave heights versus wind speed based on the Beaufort scale. Also plotted on the graph is a modified wave height where the height increase is proportional to the sum of the wind and current velocities squared. A two knot current is used and using the square of the velocities is a conservative assumption. For waves greater than 5 ft, the increase in wave height varies decreasingly from 25% to 10% of the zero current wave height. As the wind velocity increases, it can be seen that the relative contribution from the current decreases in magnitude. This suggests that the effects of current are significant.



Conclusion

References 1 and 3 present the best known data on the locations of interest. The locations with the most limited or suspect wind data are Chatham Straits, Lynn/Icy/Chatham Junction, Clarence Strait, Revillagigedo Channel, and Dixon Entrance. We recommend that better wind data be obtained in order to accurately predict wave characteristics at these locations. For any following studies, the sea state should be estimated with methods that account for fetch, wave development time, and the local geography. Several computer programs exist that could make this possible such as NARFET, STWAVE, and SWAN.

Chart - Weather Station Data



TASK 2 – ROUTE ANALYSIS

Using available environmental data, we estimated the annual 99 percentile values for sea state along various potential ferry routes in Southeast Alaska.

Procedure

Reference 1 gives 99 percentile wave heights for various locations which are listed below. Using the Pierson-Moskowitz Sea Spectrum table, the corresponding sea state is listed.

Results

Route	Length (nm)	99^{th} Wave Height (ft)	Sea State
200-300 miles			
Ketchikan-Petersburg	222	6.9	4.5
Sitka-Juneau	264	7.1	4.6
Juneau-Petersburg	246	6.3	4.2
120-200 miles			
Prince Rupert-Ketchikan	190	5.6	3.8
Ketchikan-Wrangell	178	6.9	4.5
Angoon-Juneau	156	7.1	4.6
Sitka-Angoon	152	7.1	4.6
Juneau-Hoonah-Gustavus	126	7.1	4.6
Juneau-Haines	136	6.6	4.3
Juneau-Haines-Skagway	162	6.6	4.3
Under 120 miles			
Ketchikan-Hollis	80	5.5	3.8
Coffman Cove-Wrangell-South Mitkoff	92	6.9	4.5
Wrangell-South Mitkoff	24	1.2	1.2
Juneau-Hoonah	96	7.1	4.6
Haines-Skagway	26	5.9	4.0

Conclusion

The results show the significant wave height which will not be exceeded 99% of the time. This is an appropriate baseline to begin design of new vessels or route selection with existing vessels because this size of wave is an appropriate standard for passenger comfort calculations.

TASK 3 – STUDY VESSELS

We were asked to gather data on four classes of vessel that are representative of the kinds of vehicle ferries suitable for Alaskan service. The vessels are the AURORA/LECONTE class, the E. L. BARTLETT, the PRINCE OF WALES/STIKINE class, and the LITUYA. We compared each of the classes of vessels against the routes specified in Task 2. The vessels were scored with regard to service reliability, carrying capacity, and service schedule (speed).

Procedure

We gathered data on the vessel particulars from various sources including our own archives, since EBDG and our predecessor firm, Nickum and Spaulding, designed three of the four classes. Operating cost data was provided by the Alaska Marine Highway System and the Inter-Island Ferry Authority (IFA). The procedure for the seakeeping analysis is given in Appendix A.

Description

The ferries AURORA/LECONTE (right) were constructed for AMHS in 1977 and 1974, respectively. They have operated for over 30 years in Southeast and South-Central Alaska, serving as a vital link between the smaller communities and the larger ports. The vessels are steel monohull designs with enclosed vehicle decks. The vessels are equipped with forward side loading doors and aft stern doors. There are overnight accommodations for the crew only. The vessels operate 24/7 on route segments that generally are 8 hours or less in duration.

The ferry E.L. BARTLETT (left) was constructed for AMHS in 1969 specifically for operation in Prince Williams Sound and was retired after 35 years of service. The vessel was a steel monohull design with an enclosed vehicle deck. The vessel was equipped with a bow loading door and aft stern door. There were overnight accommodations for the crew only. The vessel operated 24/7 on route segments that were generally 8 hours or less in duration.

The ferries PRINCE OF WALES (right) and STIKINE were constructed for IFA in 2001 and 2006, respectively. They operate as day boats between Ketchikan and Hollis, or up in Sumner Strait between Coffman Cove, Wrangell, and Blind Slough (Petersburg). Their mission is to link Prince of Wales Island with other communities in Southeast Alaska. The vessels are steel monohull designs with enclosed vehicle decks. The vessels are equipped with forward side loading doors and aft stern doors. There are no overnight accommodations onboard. The vessels operate on route segments that generally are 4 hours or less in duration.

The LITUYA (left) is the newest of the AMHS ferries. Delivered in 2004, the vessel design was modeled after oilfield supply boats with a forward superstructure and an open vehicle deck. The vessel operates as a day boat between Metlakatla Island and Ketchikan. There are no overnight accommodations onboard. Vehicles are loaded over the side and over the stern.

All of the four classes of vessel can handle a range of vehicle traffic including cars, pickup trucks, campers, and tractor/trailer trucks.

Vessel Particulars

CLASS/ Year Built	CAPACITY	LOA	DISP (LT)	SPEED (kts)	POWER	VEHICLE DECK	ENGINE TYPE
AURORA/ 1976	40 cars	232'-0"	2130	16	2 x 2150	enclosed	med speed
BARTLETT/ 1968	30 cars	189'-6"	1320	14	2 x 1734	enclosed	med speed
STIKINE/ 2003	30 cars	194'-4"	1140	15	2 x 1500	enclosed	high speed
LITUYA/ 2002	20 cars	170'-6"	850	12	2 x 1000	open	high speed

Capital Cost

Below the original capital cost of each vessel is given, along with the year in which it was built.

CLASS	LIGHT SHIP [LT]	YEAR BUILT	CAPITAL COST (Million USD)
AURORA	1453	1976	7.700
BARTLETT	1051	1968	3.200
IFA	932	2003	13.100
LITUYA	600	2002	9.547

Maximum Operating Conditions

Maximum Operating Conditions are defined here as the Sea State which causes a Motion Sickness Index (MSI) of 20% at t=2 hours at the design speed, meaning after 2 hours of sustained seas at this level approximately 20% of un-acclimated passengers will become sick. The ranking of vessel performance is based on the MSI ranking at the vessel's design speed in seas with 7.1 foot significant waves, which corresponds to the worst 99th percentile wave in the winter in Southeast Alaska.

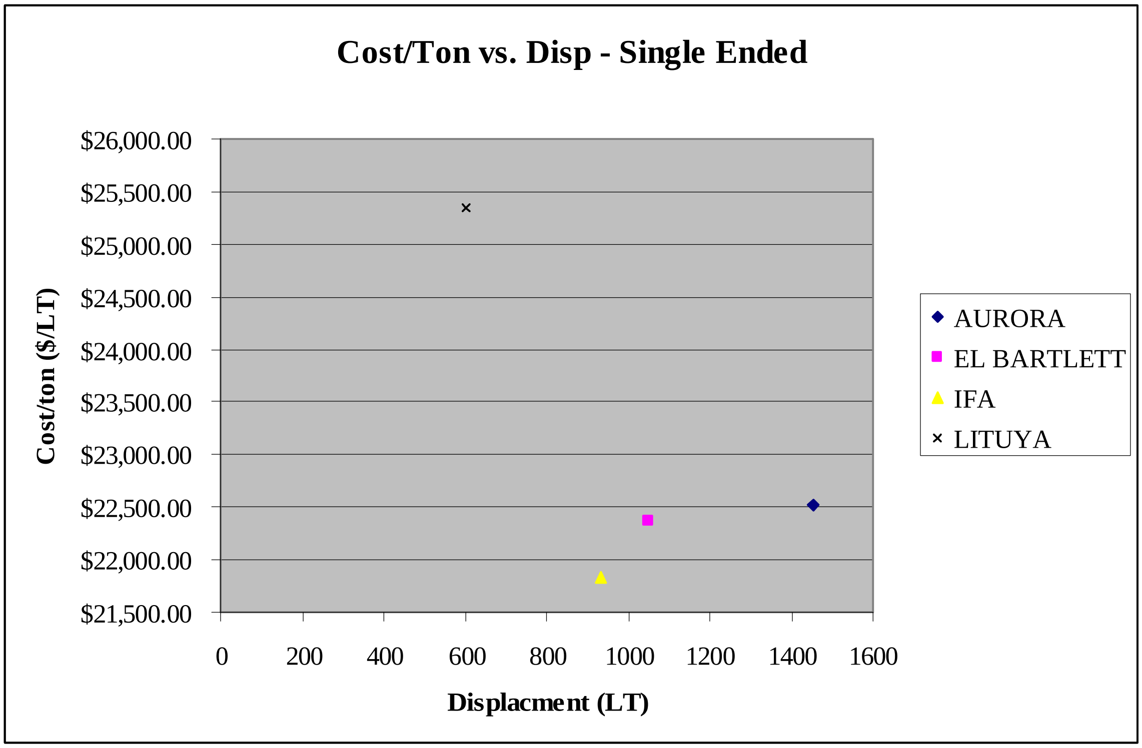
Vessel	Max Sea State	Design Speed (kts)	MSI, Hs=7.1	Rank
Aurora	5.0	16	10%, t=4 hrs	1
Bartlett	3.9	14	10%, t=2 hrs	2
IFA	2.3	15	35%, t=2 hrs	4
Lituya	3.1	12	20%, t=2 hrs	3

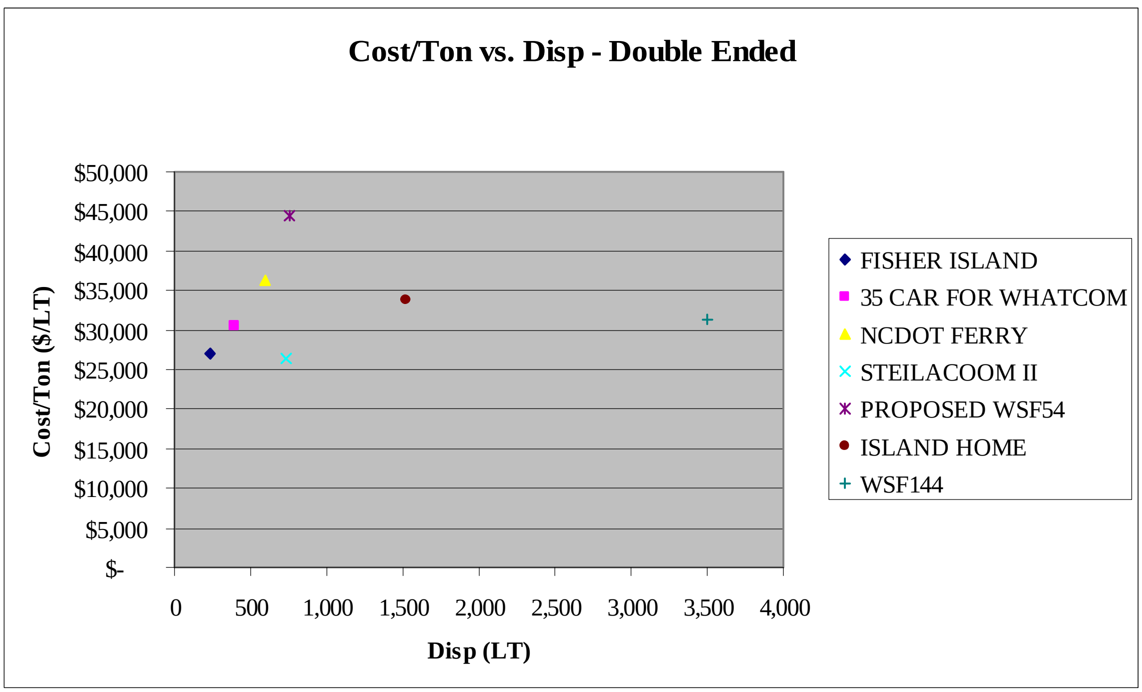
Note that these results are specifically for the worst location in Southeast Alaska, which is the convergent zone of weather from Lynn Canal and Icy Strait. Also note that the fact that because the wave is a 99th percentile wave does not mean that 1% of the time the noted MSI will be reached. It will actually be less than this because the 99th percentile Hs wave will not be likely to persist for 2 and/or 4 hours of the voyage. This would require further study to find the length of time over which the waves persist and their effects on seasickness.

Class Costs

As-bid construction prices were gathered from various sources for each class. These were converted to 2009 dollars using the Index of Estimated Shipbuilding Costs (Reference 4) and the Bureau of Labor Statistics (BLS) Self propelled ships, new, nonmilitary index (Reference 5).

Clearly, the construction cost increases as vessel displacement increases. The cost/ton appears to vary linearly with the overall displacement of the vessel. In other words, there does not appear to be reduced costs due to economy of scale in terms of construction cost of ferries. This is shown both with the subject vessels and double-ended ferries for which there is more information available. Double-ended ferries cost more per ton than the subject single-ended ferries, but the lack of a trend reinforces the notion that cost per ton does not change depending on displacement.


Cost/Ton vs. Disp - Single Ended
Cost/ton ($/LT)
$26,000.00
$25,500.00
$25,000.00
$24,500.00
$24,000.00
$23,500.00
$23,000.00
$22,500.00
$22,000.00
$21,500.00
0
200
400
600
800
1000
1200
1400
1600
Displacment (LT)
AURORA
EL BARTLETT
IFA
LITUYA


Cost/Ton vs. Disp - Double Ended
Cost/Ton ($/LT)
$50,000
$45,000
$40,000
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$-
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
Disp (LT)
FISHER ISLAND
35 CAR FOR WHATCOM
NCDOT FERRY
STEILACOOM II
PROPOSED WSF54
ISLAND HOME
WSF144

Operating Costs

Operating Costs are given in Appendix B.

Operating cost data is also collected from the AMHS Annual Financial Report (shown below). The numbers express the total cost to operate the vessel and the breakdown is not as clear as with the data from other three vessels. This data can still be used to show the relative costs of operating the vessels. In particular, this data is used to compare the BARTLETT to the AURORA and is found to have operating costs of approximately 65% of the AURORA's operating cost.

Alaska Marine Highway System

Operating Expenditures by Vessel* FY 1994 - 2005

(In Thousands)

Vessel	FY94	FY95	FY96	FY97	FY98	FY99	FY00	FY01	FY02	FY03	FY04	FY05
Aurora	4,270	5,536	5,221	3,820	5,115	5,161	6,141	4,849	3,673	4,379	5,565	3,533
Bartlett	4,530	3,523	3,896	2,970	3,071	2,717	2,874	3,000	2,882	4,274	1,032	
Chenega												314
Columbia	6,910	9,081	11,731	9,607	8,470	8,047	6,190	1,851	5,946	7,917	7,787	7,336
Fairweather										-	692	5,635
Kennicott	-	-	-	-	858	10,365	11,130	12,974	10,780	12,483	9,744	9,535
LeConte	5,530	5,037	5,457	5,885	5,042	5,564	4,630	6,767	6,392	6,490	4,037	5,869
Lituya											177	629
Malaspina	6,600	9,743	9,760	9,995	6,351	3,639	4,206	6,296	4,265	4,432	10,131	11,492
Matanuska	9,600	6,357	7,100	5,561	9,298	6,606	10,392	7,926	10,780	10,920	5,018	11,202
Taku	9,180	8,791	5,278	9,676	8,627	8,757	6,628	10,188	9,249	9,492	8,709	4,107
Tustumena	3,690	5,501	4,060	5,767	5,486	5,899	6,135	6,674	6,396	5,433	5,483	6,269
Vessel Leave											9,824	9,204
All Vessels	7,301	5,137	5,782	6,364	6,566	7,169	7,156	8,797	8,188	8,185	9,078	13,904
TOTAL ALL	**57,611**	**58,707**	**58,285**	**59,645**	**58,884**	**63,924**	**65,482**	**69,322**	**68,551**	**74,005**	**77,275**	**89,028**

13

*Expenditures by vessel include the operating budget components vessel operations and overhaul plus unbudgeted reimbursable services agreements. Not included are the budget components for terminal operations, reservations and marketing, and administration.

Operating Schedule

Due to the large number of small cities and locations in Southeast Alaska, Alaska ferries are mainly run as 24-hour boats to service the maximum number of destinations per boat. These routes are usually very long and require 2 or 3 shifts to operate. In some cases, it becomes less expensive to design a vessel to run faster (at increased operating cost) and employ fewer crew members per day. Vessels traveling on such schedules are known as day boats. Studies have shown that the savings in crew costs can be greater than increased fuel cost when a day boat operation is possible. In order for day boat operation to be possible, the following route characteristics must generally be present:

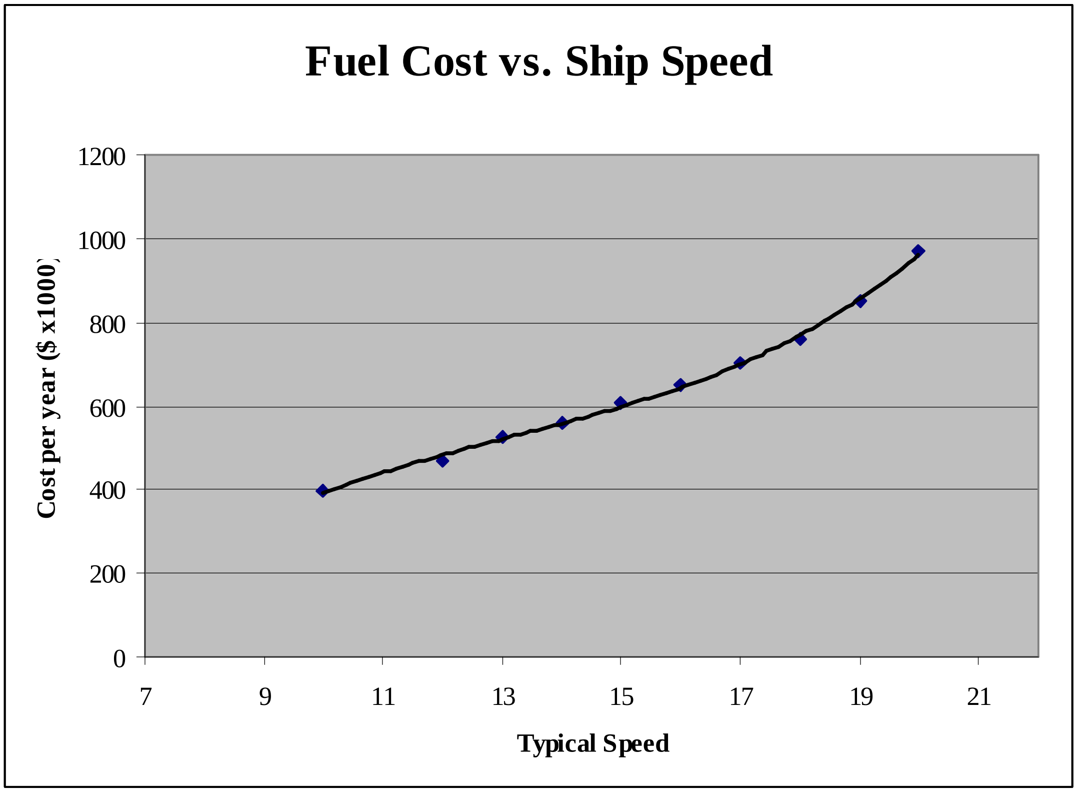
1. The two destinations must be close enough together so that the route can be completed in a single 10-hour shift by the vessel's crew.
2. Other features (such as tidal restrictions) must not interfere with completion of the route within a single shift.

3. The two destinations should have enough traffic to make the dedication of the vessel to a single route economical.

Vessel Speed

Propulsion power vs. Speed for vessels of this type in this speed range is basically a third-order polynomial relation, which in practical terms means that a given increase in speed has a more than proportional increase in fuel consumption. For this reason, it is desirable to design the ship speed to be as low as possible with respect to the limits on schedule and crew availability.

The fuel graph below is based on the variation in brake specific fuel consumption vs. speed for the Alaska Class Ferry, and normalized to the cost in fuel per year of the IFA ferry at a normal running speed of 14 knots. In terms of cost vs. speed, this means that this prediction may under predict the cost at speeds above 14 knots because the IFA ferry is a shorter vessel than the Alaska Class Ferry and, therefore, approaches hull speed at a lower speed where resistance trends upward more quickly.



This evidence shows that speed should be reduced to the lowest speed possible while still making schedule, because a reduction in speed reduces fuel cost more than it increases crew cost. If the class is not expected to be needed on routes where a faster speed is required, the engine should also be sized as small as possible, with respect to maneuvering requirements, to save on the capital cost of the engine.

We prepared an estimate of the yearly reduction in expenses for each knot of reduction in speed for a 5,000 BHP ferry. This route is assumed to be a 24-hour schedule with 4 hours per day of idle time. Yearly fuel and crew wage data are taken from the IFA ferry and adjusted for 2009 dollars. Fuel consumption data is based on two 2,500 BHP engines. The applicable range of speed is highlighted in blue. For each knot of reduced speed, fuel consumption can be reduced by approximately 10-15% per running hour. The data shows that per knot of reduced speed the fuel savings are about twice the amount of increased crew wages.

Vessel Size

For a given hull envelope, fuel costs vary linearly with displacement. Studies on the Alaska Class Ferry indicate that for a decrease in weight of 1%, the fuel consumption will be reduced by approximately 0.7%, with an expected similar trend for ferry vessels of other sizes. Specifically, for the Alaska Class Ferry this amount is approximately $13,000 per year, or $325 saving per year per ton of reduction.

The linearity of fuel cost changes per weight change breaks down when large changes to vessel size are made, because the hull envelope will be further optimized. This means, for example, that if the vessel size is greatly increased, the waterline length will increase and, therefore, the residuary resistance coefficient will be reduced. This means that the increased fuel cost per ton of weight growth diminishes over large weight increases.

Results

Scoring

The Classes are ranked 1 through 4 for service reliability, carrying capacity, and service schedule. Service reliability ranking is based on the vessel that can operate in the largest sea state. Carrying capacity is based on the vessel with the more lane feet. Service schedule is based on the vessel that has the fastest service speed.

SCORING CLASS	SERVICE RELIABILITY	% of AURORA	CARRYING CAPACITY	% of AURORA	SERVICE SCHEDULE	% of AURORA	SEA-KEEPING
AURORA	1	100%	1	100%	1	100%	1
BARTLETT	2	83%	2	88%	3	88%	2
IFA	3	67%	3	88%	2	94%	4
LITUYA	4	50%	4	53%	4	75%	3

SCORING CLASS	ANNUAL COST	% of AURORA	CAPITAL COST	% OF AURORA
AURORA	4	100%	4	100%
BARTLETT	3	65%	3	72%
IFA	2	21%	2	62%
LITUYA	1	15%	1	47%

TASK 4 – VESSEL COST FACTORS

This section identifies factors that affect capital and operating costs for vessels which are approximately 170'-240' long, having a vehicle capacity of 20-50 vehicles, running at 12-16 knots, and having a route length of less than 300 nm.

Procedure

Class particulars and cost information from vessels in this small to medium size range were gathered to identify generic factors that affect capital and operating cost. Operating costs include personnel, fuel, maintenance/overhaul, commodities, and a portion of the overall fleet's indirect expenses. The reference vessels and their particulars are listed in Task 3 above.

Conclusions

Capital Cost Factors

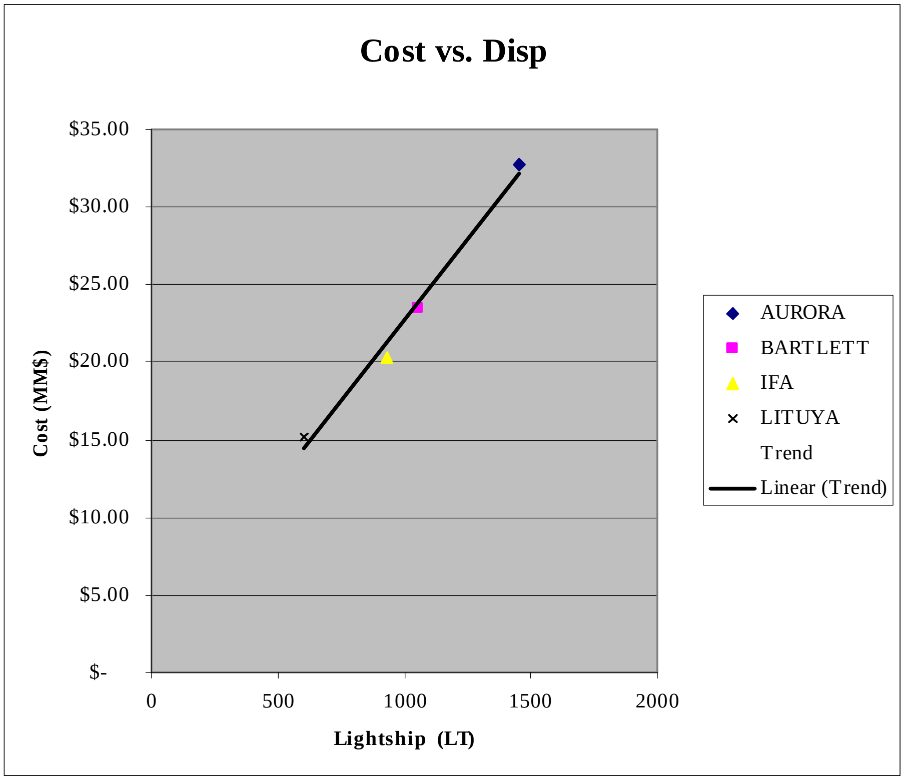
Vessel Weight - Class Capital Cost increases linearly with Class Light Ship Weight. Class Capital Cost also increases with Carrying Capacity.

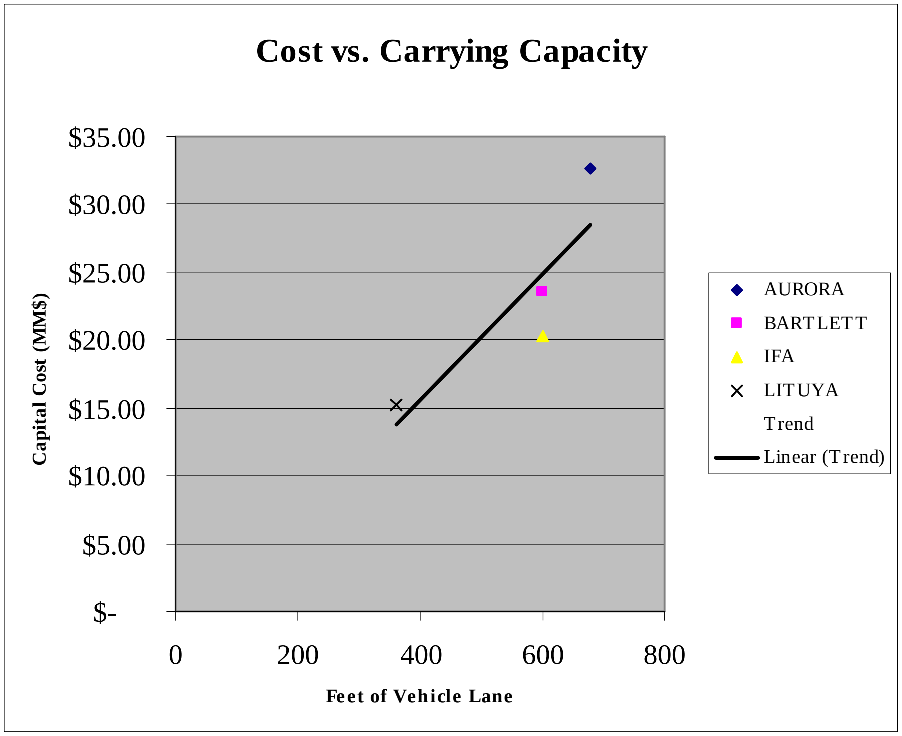
Vessel capital cost is closely related to the weight of the vessel when we are comparing steel construction to steel construction. A vessel of twice the light ship weight will generally cost twice as much as a lighter vessel of the same type. A more sophisticated breakdown, such as we use for concept design work, divides the weight into six basic categories: 1) structure, 2) propulsion machinery, 3) electrical plant, 4) electronics, 5) auxiliary systems, and 6) outfit (furniture, linings, ceilings, doors, etc.). This allows us to discriminate between a slow vessel with lighter weight propulsion machinery from a fast vessel, which will have proportionately greater machinery weight. Each of these weight categories is then assigned a cost factor except for electronics, where a cost is assigned, since the cost of electronics can vary greatly without significant changes in the weight. Another area where there can be significant variation in the cost is outfit. This can range from very "bare bones" to quite elaborate. Certainly, the amount of outfit and associated cost is affected by the need for overnight accommodations, either for crew or passengers. If possible, the elimination of overnight accommodations is recommended for shuttle ferries on short routes where the crews can berth ashore.

The table below shows the capital cost of each class adjusted to 2009 dollars. The adjustment to 2009 dollars is equal to the ratio of the indices of shipbuilding costs & labor between 2009 and the year the specific class was built.

COSTS		
CLASS	LIGHT SHIP [LT]	CAPITAL COST (2009 dollars)
AURORA	1453	32.710
BARTLETT	1051	23.502
IFA	932	20.346
LITUYA	600	15.212

Graphs of Class Capital Cost vs. Light Ship Displacement and vs. Feet of Vehicle Lane are given below. With Light Ship, there is a very linear trend in Capital Cost. There is also a clear upward trend with increased vehicle capacity which appears somewhat linear, but is difficult to say with limited data.





Open/Enclosed Car Deck - Where passenger comfort or vehicle protection on a route does not demand an enclosed vehicle deck, an open vehicle deck should be considered to save on construction costs.

Protection of passengers and their vehicles is a high priority. The Alaska Marine Highway System has had a history of ferries with enclosed car decks, beginning with the CHILKAT until the construction of the LITUYA. Whether the ferry should be constructed with open decks is more dependent upon the length and weather exposure for the route, than it is upon the capital cost. For short routes, where there is limited weather exposure, we would recommend that an open vehicle deck configuration be given consideration. An open vehicle deck can save on both capital costs and operating costs by reducing weight and increasing fuel efficiency. An open deck also allows for over height vehicles or unique cargos.

Where the weather is rough enough to cause damage to vehicles or deck cargo, it is recommended that an enclosed vehicle deck be required. There is no doubt that an enclosed vehicle deck is more expensive to construct since it requires additional steel, ventilation, a sprinkler system, lighting, closure doors, paint, fire detectors, etc. An enclosed vehicle deck can also reduce maintenance costs on deck equipment by protecting the equipment from corrosive saltwater spray, as shown by the photo of the LECONTE below. This can be especially important in winter conditions when ice is formed.

The life of the vessel and safety of the crew are improved by enclosing deck areas for the following reasons:

- Mooring lines are protected.

- Paint coating systems experience less exposure to harsh conditions.
- Crew members can check vehicles out of the weather.
- Piping systems are protected from freezing temperatures.

Vehicle Loading Scheme - If enough time is spent in port loading/unloading operations, it may become a net cost savings to include a bow door to reduce load/unload times at the loss of increased construction cost and reduced fuel efficiency.

It is possible to reduce vehicle load time from that of a design with a stern/side door configuration by installing a bow door, so that vehicles will be able to drive straight on and straight off instead of rounding a difficult corner.

The cost of the bow door relative to a vessel with a stern/side door configuration is $150,000 to $200,000 greater. The bow doors would be a net cost savings, if the cost of construction plus the yearly cost increase in fuel are not greater than the reduction in other operating costs. Studies on the Alaska Class Ferry indicated that installing a bow door reduces hull efficiency and increase fuel consumption by 3-5%. Currently, crew costs are twice fuel costs. If use of the bow door reduces crew hours by 1-1/2% to 2-1/2%, then the bow doors would be recommended. However, crew members are generally paid for quantum levels of labor, i.e. a 12-hour day or a 16-hour day. If use of bow doors effectively reduces operating time by 3.1% (from 16 hours to 15.47 hours), then the crew will likely still be paid for 16 hours of labor. Even if we consider 6 port calls per day and the associated labor hour reduction of 9.4%, that still only reduces the operating time from 16 hours to 14.50 hours. Note also that an increase in fuel costs will change the break-even point.

The question of whether to use bow doors needs to be examined with regard to both vessel and terminal cost, flexibility in assigning vessels to different routes, and the dynamics of a particular route. The closer the ports are together, the more benefit there is to a "drive-through" configuration. For example, when British Columbia Ferries (BCF) was analyzing their need for new ferries they looked at the route from Horseshoe Bay to Nanaimo, a distance of some 30 nautical miles. The ferry was planned to make 3 round trips per day with an average voyage time of 1 hour 40 minutes. Due to the number of port calls (6) and the distance between the ports, BCF elected to build double-ended ferries for efficiency of loading and unloading. If the route had been longer with fewer port calls per day, such as on their northernmost route to Prince Rupert, a single-ended ferry would have been the preferred choice.

Passenger Loading Scheme - Passenger loading modifications can save significant time. This time saving could be used to improve schedule and reduce personnel costs, or to reduce speed and reduce fuel costs. The cost of constructing a separate passenger ramp system should be analyzed against the potential cost benefits.

Passengers are normally loaded via the vehicle ramp, meaning that the vehicles and passengers cannot be loaded at the same time. In order to allow the passengers to load at the same time as the vehicles, a separate passenger loading ramp could be designed and save a significant amount of time at each destination. The increased cost to the class would be negligible. Cost to modify the terminal facility may not be negligible, especially given ADA requirements and the large tidal range. Further, the time savings is proportional to the number of foot passengers carried. If the majority of passengers are loaded aboard in vehicles, then the time required to load a few foot passengers may be negligible.

Allowable Vehicles - Without compromising the goals of the AMHS, which is to provide transportation to any highway vehicle, it would not be possible to limit the vehicles which are allowed on board. When class size or shore side facilities otherwise limit the type of vehicles that can be loaded, limiting vehicle size may increase fuel efficiency and reduce load/unload time.

The mission of the AMHS is to provide transportation to highway vehicles across water. Ideally, this means that any highway vehicle should be provided transport by any AMHS vessel. However, the types of vehicles allowed on small to medium-sized ferries can have a significant impact on the layout of the vehicle deck, the size and location of loading doors or ramps, and the structural design of the vessel. For example, the older Alaska ferries such as the E.L. BARTLETT were designed for a maximum vehicle height of 14 ft, while more recent ferries have been designed for vehicle heights of 15 ft 6 inches. This results in raising the profile of the ferry which impacts stability, increases wind resistance, and requires more structure, thus adding weight.

Due to the deep waters typically found near shore in Alaska, many of the existing ferry terminals have used side loading of ferries in order to reduce the capital cost of the terminals and the challenges of securely mooring a vessel. This loading configuration makes the handling of long vehicles, such as tractor trailer units or large motor homes, challenging and results in ferries that are relatively wide for their length. Vessels with low length-to-beam ratios generally are less fuel efficient than slimmer vessels. Further, to accommodate the turning radii of long vehicles, the vehicle deck arrangement may compromise the location of elevators, or stairways for passengers. For these reasons, bow loading is an attractive option for smaller vessels that operate on shorter routes where the efficiency of loading/unloading can be critical to meeting schedule. For example, if the loading/unloading can be accomplished in 30 minutes rather than 60 minutes, the vessel may be able to operate at a slower speed and thus save fuel and produce fewer emissions. For any new ferry operation, the Owner should give careful consideration to the sizes of vehicles, the configuration of the vehicle deck, and the impact on the terminals.

Aluminum Superstructure

Many modern ferry designs use aluminum for part, or all, of the structural material. While aluminum, as a substance, has 1/3 the density of steel, it is also less strong and loses strength at relatively low temperatures compared to steel. This means that, for equivalent strength, the aluminum has to be thicker and has to be insulated for fire protection. These changes typically result in a structure that is 2/3 the weight of an equivalent steel structure. The material cost for steel per lb is roughly 1/3 the material cost for aluminum while the labor to shape and erect aluminum panels is somewhat less for aluminum than for steel panels. The net result is that steel construction will always be less expensive that aluminum construction. Because the vessel light ship weight will decrease with aluminum, the propulsion plant can be somewhat decreased in size which will offset some of the increased structural cost for aluminum. Typically, aluminum is used for the upper structure in a ferry, such as funnels, masts, or deck houses, in order to minimize the weights high in the vessel and thus improve the stability. The joint between the steel and aluminum structure is typically made by welding to a bi-metallic strip formed by explosion bonding of steel and aluminum. Aluminum structures require less maintenance since they do not rust.

<u>Operating Cost Factors</u>

The same factors that affect capital cost (size and weight of vessel, speed and size of propulsion plant, extent of accommodations for passengers and crew) also affect operating costs. A heavier boat takes more fuel to move it through the water. A faster boat takes more fuel and more machinery maintenance. A boat with extensive accommodations has more plumbing, wiring, linings, handrails, lights, etc, all of which require maintenance. <u>To reduce costs, the vessel should be as simple as the mission will allow.</u>

Design choices that will reduce operating costs are listed below. Note that these design choices may also affect reliability and risk.

- Operate the vessel as a day boat with no overnight accommodations for either passengers or crew.

- Minimize the number of prime movers (diesel engines) that have to be installed.

- Keep the admeasured tonnage under 100 gross tons so the vessel can be designed and constructed to the requirements of 46 CFR Subchapter K or Subchapter T, depending upon passenger capacity.

- Install energy efficient lighting, pumps, fans, and heating systems to minimize the electrical loads.

- Install extra insulation and double or triple pane windows to minimize heat loss.

- Minimize the number of passenger decks to minimize the need for crew patrols and reduce the possibility of vandalism.

- Avoid enclosing the vehicle deck to decrease the structural weight, eliminate the need for ventilations systems and weathertight vehicle doors, and minimize the need for fire extinguishing systems.

- Design the vessel with an unmanned engine room, but not to ABS unattended machinery space classification.

- Minimize loading/unloading times in order to require the least speed to maintain a required schedule. This has greater benefit the more times the vessel docks in a day.

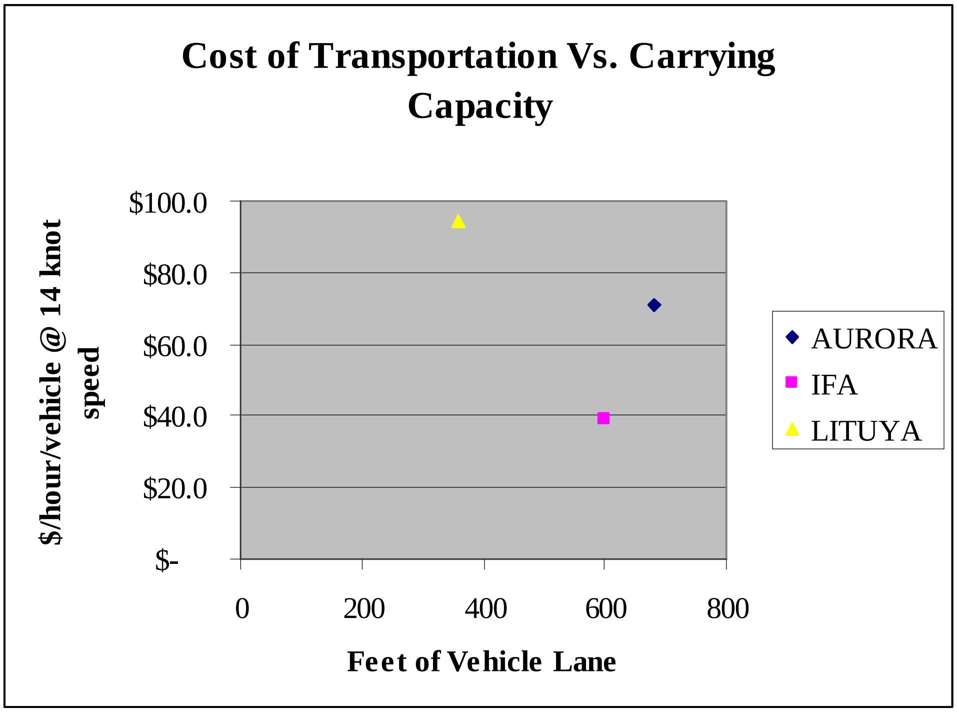
- Minimize the degree of redundant and/or interconnected systems within the service model of the operation. For example, if the intent is to operate the vessel with one diesel generator down for service, then a minimum of three generators will be required.

- Minimize the number of auxiliary systems required. If the black and gray water can be pumped ashore for processing, that eliminates the need for a marine sanitation device (MSD). If the engines are small enough for battery start, consider eliminating the compressed air system. Instead of separate interior communication systems, use a combined public address and general alarm system when the regulations allow.

Vessel size versus service reliability is discussed below. If the vessel is sized to the traffic demand, AMHS must ask of their customers whether a reduced reliability of service is acceptable, especially during the winter months. If a vessel can make 99 out of 100 scheduled trips in the summer, but only 80 out of 100 trips in the winter, does that reach an acceptable level of service? How should the ferry compare with other publically funded transportation such as the highways? These are policy questions, not design questions.

Vehicle (ASD) Capacity - Operating Cost per vehicle per operating hour is reduced in larger vessels. The class should be designed to be as large as possible to increase this cost efficiency as long as it is still able to maintain maximum utilization.

Operating Cost vs. Carrying Capacity is expected to trend downward due to economies of scale. Below is a graph that presents the cost in dollars per vehicle per running hour of transport, vs. the vessel carrying capacity expressed in feet of vehicle lane. The AURORA and LITUYA fit the expected trend with a significantly less expensive cost of transportation for the larger AURORA. The IFA ferry has lower crew costs, and operated on a more consistent schedule over the time period from which data is available. It is expected that for the AURORA and LITUYA, the cost of transportation will be reduced to values approaching that of the IFA if the number of operating hours per year is increased.



This evidence shows the connection between efficient route planning and reduced cost of transportation. By planning a fleet which is appropriately sized to the demands of the specific routes of Southeast Alaska, the number of operating hours per year can be maximized and reduce expenses.

Hull Form - A CFD Analysis is a good way to analyze hull form to optimize flow characteristics. The addition of a bulb is a proven way to reduce resistance, especially for classes designed for routes with consistent speed and loading.

Fuel costs can be reduced with an optimized hull form. Optimizing the hull shape based on a CFD analysis can reduce resistance.

A bulbous bow addition is appropriate for ferries when they are operating at a fairly uniform speed and draft through the majority of their operation hours. When a bulb is fit to a hull that has an otherwise well-designed bow, reduction in power/fuel savings can range from 2-5%. Bulbs are often most effective within a 3 knot range around the design speed. If a vessel deviates from this range, the savings will diminish and may actually increase the power/fuel consumption.

<u>Personnel Cost Factors</u>

Operating Schedule

The overhead cost of hiring additional crew is usually higher than the cost of paying existing crew overtime. Increasing vessel speed <u>to prevent the necessity of hiring a second crew shift</u> usually reduces crew expense more than it increases fuel cost.

Typically, Southeast routes operate on a continuously rolling schedule so that the odd route lengths do not need to fit into a daily schedule. In these cases, 2 or 3 separate crews are kept on board to change shifts as needed.

Some route lengths are such that, depending on vessel speed, the length of the day may necessitate that either one crew be paid overtime to work up to 12 hours, or a second crew be brought on board to relieve the first at the end of their shift. The Glosten VSS and conversations with ADOT&PF indicate that because of the overhead associated with hiring additional crew, it is generally less expensive to increase vessel speed (at the loss of fuel economy) and/or pay a single crew overtime than to hire a second shift of personnel. The decision of whether to hire a second crew or pay overtime/increase vessel speed is dependent on the specifics of a given route. The route must be analyzed independently to make such a decision.

Crew Size - Reduction in crew size can greatly reduce operating cost. When the minimum crew is determined by USCG requirements, reduction in the number of lifesaving appliances and machinery room automation should be considered. (This does not mean a reduction in capacity, but rather a fewer number of larger capacity liferafts, rescue boats, etc. with the same total capacity.)

Crew size reduction provides a large opportunity for reduction in the annual operating budget. Personnel expenses account for the largest percentage of annual costs (45%). Reducing the crew by one person is estimated to reduce the annual operating budget by a minimum of $100,000.

Crew size is determined though a combination of USCG requirements and needed operations staff (such as a cook). Typically, Alaska vehicle ferry crew size is in excess of the USCG minimum because of additional onboard services such as hotel and food services. The USCG minimum is often controlled by the number of crew necessary to accomplish total ship abandonment and the number of crew required to operate machinery. This can be reduced by reducing the total quantity of lifeboats/liferafts/rescue boats necessary to accomplish the abandon ship procedure. One or more crew are required for each of these survival craft.

Vessel manning is based on various mission requirements. At the basic level, there is the number of crew required to navigate the vessel. Next there is the number of crew required to perform basic operations such as mooring the vessel, providing food service or hotel services to the passengers and crew, or controlling the loading and unloading operations. Finally, there is the number of crew required to perform safety functions such as fighting fires, launching rescue boats, or evacuating the vessel. During the design process, the design team and the operations staff must examine every crew position against the USCG-required minimums to ensure that the vessel is properly, but not excessively, crewed.

Depending upon the size, arrangement, and features of the vessel/terminal, the answer to your question on automated mooring systems will vary. I understand that with the larger AMHS vessels, mooring is a challenge and drives the size of the deck crew. Conversely, with the IFA ferry, it is the emergency scenarios that govern the total crew size. The discussion of mooring systems can’t be restricted to the vessels. Any such discussion has to include the impact on terminal costs and maintenance plus issues of compatibility on different routes. The current philosophy at AMHS is to design vessels to suit the existing terminals with an emphasis on flexibility of vessel deployment. For a shuttle ferry operation it may make sense to have dedicated vessels and terminals, but this will come at a cost.

Maintenance Cost Factors

Propulsion Configuration - Detailed analysis is required to determine the most economical propulsion system.

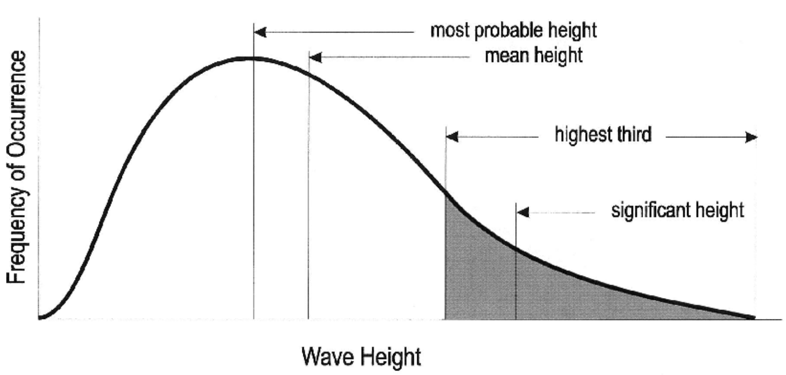
Different propulsion configurations have varying capital cost, operating cost, and reliability factors. The choice of an optimum system must reflect issues such as route length, vessel speed, size of electrical load, degree of redundancy, maintenance philosophy, etc. For a simple, reliable propulsion system most ferries use medium or high speed diesel engines, driving fixed or controllable pitch propellers through reduction gears. Electrical power generation is provided by high speed diesel generators that are independent of the propulsion system. This is the configuration used on the AMHS fleet and has proven itself well suited for their operation.

Equipment Manufacturer- When equipment is available and inexpensive enough to meet budget, it is preferable to use equipment manufactured in the U.S.A.

In general, it is preferable to use equipment produced in the U.S.A. because of availability of parts and quicker receipt of the parts when shipped. Parts from the U.S.A. will be cheaper in general, and quicker shipping times means less costly delays. However, many types of specialized marine equipment are not manufactured in the United States. This can include items such as electronics, rescue boats, controllable pitch propellers, navigation lights, etc.

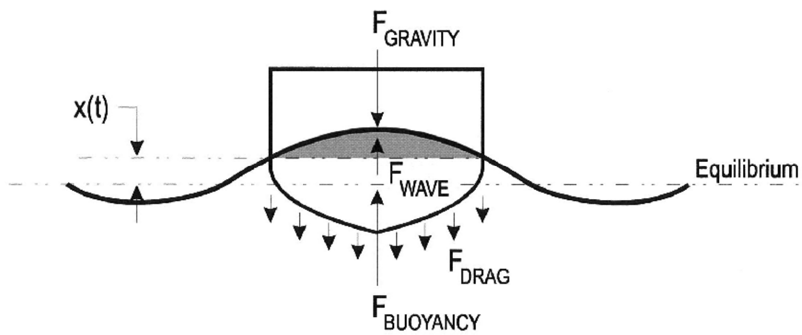
Size vs Reliability - If we build a large ferry that operates 99.9% of the time it will cost "X" amount to build, "Y" amount to operate, and will have excellent customer satisfaction. We can build a smaller ferry that operates 95% of the time that costs less to build, and costs less to operate, and has good customer satisfaction. And we can build two even smaller ferries that will cost less to build, cost less to operate, have even less customer satisfaction, but provide twice the service frequency. Where is cut-off for what is the best?

In our experience there is no cut-off. The level of service is a policy choice of the operator. If a 95% service level is deemed acceptable (one out of every twenty sailings cancelled), then that becomes the design criteria. The definition of passenger comfort is a statistical computation as shown below.



In our analysis of the weather and waves in Southeast Alaska, we have been looking at significant wave height. This is the value representing the average wave height of the 1/3 highest waves (see left). Given that waves themselves are combinations of different waves of different heights and frequencies, this means it is possible to experience a wave that is over twice the significant wave height. We have narrowed this further to look at the 99% average of the significant wave height. This means that 1% of time the significant wave heights will exceed the threshold.

Having looked at the environment that provides the energy input to cause vessel motion, we next look at the vessel's response. The vessel system can be modeled as a linear mass spring system with a dampener (see right). The vessel is the mass, the spring is buoyancy to restore the vessel to its equilibrium position as waves pass under it, and the dampener is the sum of friction, turbulence, and drag. The equation of a linear system takes the form of:



F(t) = mg + mA + cV + kD where:

F(t) = force varying over time

m = mass

g = acceleration due to gravity

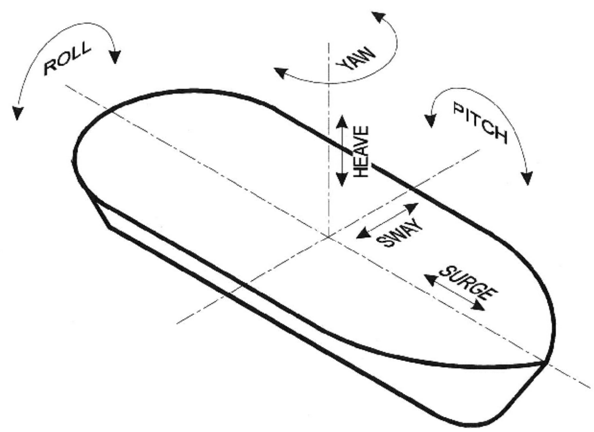
A = acceleration of the vessel

c = damping coefficient

V = velocity of the vessel

k = buoyancy

D = distance the vessel moves



Vessel Motions

Note: It is important to recognize that vessel mass is a key factor in the equation. For a given wave height, a heavy vessel will have lower accelerations or move less than a lighter weight vessel. Another factor is the damping coefficient. Adding bilge keels to a vessel increases the drag and turbulence when a vessel rolls, reducing motion. Finally, the buoyancy constant is proportional to the amount of waterplane area of the vessel. A slender spar buoy will move less than a fat can buoy.

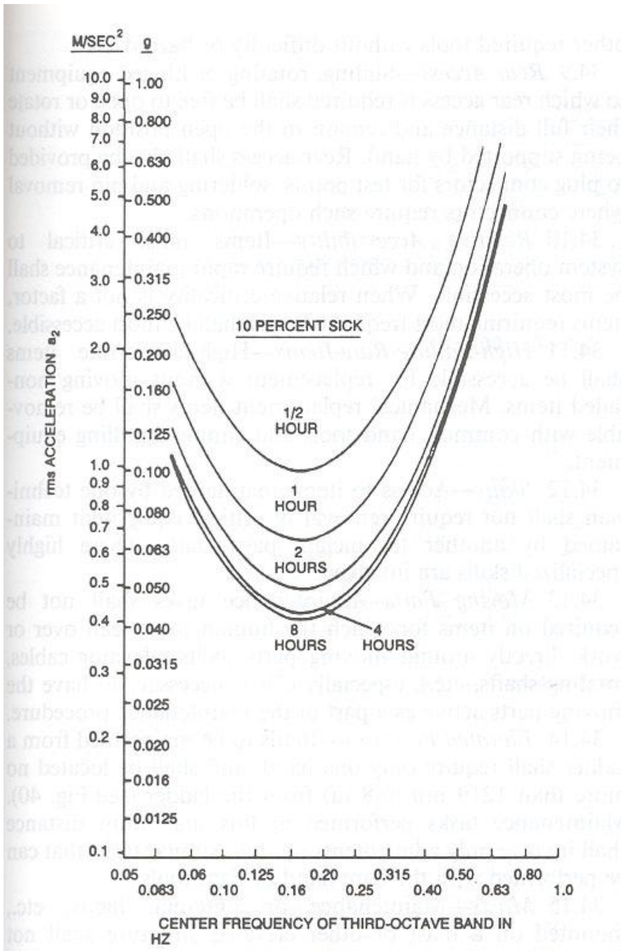


FIG. 98 The 90 % Motion Sickness Protection Limits for Human Exposure to Very Low Frequency Vibration

This response is defined at different vessel speeds and different headings relative to the direction of the waves. The response itself is a statistical probability based on the spectrum of the waves and is expressed in terms of motion in six directions, three linear (heave, sway, surge) and three angular (pitch, roll, and yaw) as shown above. For passenger comfort, we generally look at pitch/heave and roll/sway combinations since these typically are the larger motions given the typical slender shapes of vessel i.e. relatively greater in length than beam.

Once we know how the vessel responds, we can look at how the passengers respond. Of the various studies on motion sickness for vessels, the dominant factor affection nausea is vertical acceleration (O'Hanlon et al, 1973 and Price et al, 2007). Vertical acceleration will be a combination of the six degrees of motion and will vary at different locations within the vessel. For example, pitch acceleration will be greatest at the bow, while acceleration due to roll will be greatest high up in the vessel. For the purposes of this study, we have calculated vertical accelerations at the starboard forward corner of the passenger cabin for each of the sample vessels. If we wish to limit the motion discomfort to 10% of the passengers on a 2 hours voyage, we need to keep the root-mean-square of the vertical accelerations less than 0.5 meters per second squared (see above). On the other hand, if it is acceptable to have 20% of the passengers experience nausea, then the accelerations can increase to approximately 0.8 meters per second or a 60% increase.

Of our sample vessels, the AURORA has the best seakeeping response because it is the heaviest. The E.L. BARTLETT and the PRINCE OF WALES have very similar seakeeping response since the vessels are of similar size and weight. As expected, the data shows less acceleration in pitch for the PRINCE OF WALES due to its bulbous bow. The LITUYA has the greatest motion since it is the smallest of the four vessels. For a further description of the seakeeping calculations see Appendix A.

Our original statement of services included the assumption that, ". . . there must be a significant point where an additional increment of service reliability and passenger comfort is not worth the increase in both capital and operating costs." It seems that the reports we received include the information for a rudimentary analysis of that relationship or tradeoff, but there is no specific analysis concluding whether that assumption is correct or, if it is, where the break point is. Actually, in order to answer the question in through quantitative analysis, we would have to assign a value to passenger comfort, else there is no way to compare.

If we look at the history of AMHS, we can see a parallel discussion around the service of the TUSTUMENA to Kodiak Island. As originally built in 1964, the TUSTUMENA had a length overall of 252 ft. Due to passenger discomfort, the decision was made to stretch the vessel by 48 ft to her current length of 296 ft. Ferry vessels can be designed such that a length increase can be readily implemented if the traffic demand increases, or if there is a mandate to improve passenger comfort. There are also ways to shape the hull to improve ride quality, but that generally results in a greater expense for construction or a loss of speed or both. One such hull technology is the Small Waterplane Area Twin Hull (SWATH) concept that is being used for pilot boats and research vessels where minimizing motions is critical. Such technologies are generally not suited for ro-ro ferries due to the rapid changes in weight and vehicle weight distribution during the loading/unloading process.

It is worth stressing that passenger comfort is only one part of the challenge in sizing a vessel. Certainly, there is the question of vehicle capacity and design demand. By that we mean the question of: Is the design standard for the vessel based on the average demand, the peak weekly demand or the peak day? Each will yield a different size vessel. Also, is this demand based on the current traffic (if available) or some theoretical traffic projection? For example, if AKDOT/PF were looking at a ferry service across Wrangell Narrows to connect Kake to Petersburg, that service has never existed and thus has no historic data. Conversely, when we studied the new ferry system for Prince of Wales Island, which became the Inter-Island Ferry Authority, we had traffic data from AMHS service, albeit with a different service model.

TASK 5 – PLANNING FACTORS

This section is intended to provide guidelines for ADOT&PF as they consider the optimal vessel or vessels for shuttle ferry service in Southeast Alaska.

Procedure

Information developed in previous sections was used to evaluate the four study vessels on various routes. The suitability and shortcomings of each sample vessel will be presented. A process to develop an optimal design is also presented.

Conclusions

Comparison of Classes

The scoring table was presented in Task 3 above. The following descriptions give a qualitative evaluation of the study vessel ranking.

AURORA

The AURORA scored highest in all of the desirable ferry characteristic categories. Not surprisingly, it is also the most expensive both in terms of annual cost and up front capital cost. Cost/Vehicle/Hour data is limited due to lack of good data on operating times, however, it shows that the AURORA provides less expensive transportation than the smaller LITUYA (for a given running speed).

E. L. BARTLETT

The BARTLETT ranked second in reliability, capacity and seakeeping, and third in schedule. The reason it ranks lower in schedule may be because of the bow door which reduces service speed, however, the benefit to load/unload times is not clearly known and may offset the losses in transit time with faster load/unload times. The BARTLETT is the second heaviest vessel analyzed, which not surprisingly causes it to rank in second in reliability and capacity. Weight has a positive effect on seakeeping ability, as heavier vessels are not as easily accelerated by large seas as smaller vessels.

IFA

The IFA ferry is the second largest vessel in dimensions, but ranks third in weight. It has the same nominal vehicle capacity as the BARTLETT, but can carry vehicles that are longer and with a greater height. The IFA ferry scored second in service schedule. The IFA ferry is less expensive to build than the BARTLETT due to its lighter weight, high speed engines, and lack of a bow door. It would be a better choice than the BARTLETT when routes are longer and loading/unloading times are less critical. Lower manning requirements give the IFA ferry the least expensive Cost/Vehicle/Hour of the example classes.

LITUYA

The LITUYA, which is the smallest and slowest of the vessels, ranked last in all categories except seakeeping, in which it was ranked third. The LITUYA is also the most inexpensive vessel to run. It has an operating cost approximately $1/7^{th}$ of the cost of the AURORA, yet has half of the AURORA's vehicle capacity. This is mainly due to the fact that it has a smaller crew and a much slower speed, which drastically reduces fuel consumption. The LITUYA is more ideal for shorter runs with limited demand where high speeds are unnecessary.

What improvements would EBDG make on these sized ferries (the 4 studied), if they were building new ones, to make them more efficient and less costly?

Two of the vessels (BARTLETT and AURORA) were constructed to meet the USCG requirements for large passenger vessels as regulated by 46 CFR Subchapter H. These vessels were also constructed over 30 years ago (1968 and 1976 respectively). The other two vessels, both of recent construction (less than 10 years), are regulated under 46 CFR Subchapter K which applies to vessels of less than 100 gross tons carrying more than 150 passengers (PRINCE OF WALES or STIKINE), or under 46 CFR Subchapter T which applies to vessels of less than 100 gross tons carrying 150 or fewer passengers (LITUYA). These vessels were designed and constructed to minimize capital cost. If any of these four were constructed today, here are some areas for improvement:

- Where possible, eliminate overnight accommodations for the crew. Such facilities are expensive to construct, add weight, and are additional portions of the vessel that need maintenance.

- Look at the use of shaft generators to reduce fuel consumption. By operating the main engines as the sole sources of power when underway, the fuel consumption of relatively lightly loaded diesel generators can be replaced by a slight increase in main engine power. This adds operational complexity but reduces fuel and emissions.

- Apply current energy management technologies to reduce the consumption of fuel. This includes extra insulation to reduce heat loss, LED or compact fluorescent bulbs, variable speed electric motors for fans and pumps, and smart technology for turning off lights or changing environmental set points as the demand varies.

- Use computational fluid dynamics (CFD) to optimize the hull forms. By balancing the seakeeping performance and the desire for minimal resistance through the use of parametric hull geometry, we can create hull forms that are better today than those we could create even 10 years ago.

- Design the vessels to minimize all discharges. Gray and black water would be retained in larger tanks to avoid discharge while in port. When underway, the sewage would be processed through an advanced filtration system before the technical water was discharged overboard. Deck run-off would also be collected and processed where possible to minimize the risk of oil leaks from vehicles finding their way into the environment. The vessels would be design with little or no ballast to avoid the need for ballast water treatment or discharge. The engine exhausts would be passed through particulate filters and possibly a catalytic converter to minimize the discharge of Sox, NOx, and particulates.

- Design the vessels for minimum manning. Use technologies such as automated machinery spaces, self-service food facilities, and automatic mooring systems to reduce crew demands without compromising safety.

Vessel Service Life

Vessel service life - Is it better to build a new ferry with a 25-year service life (that will go away in 25-years, and then build a second 25-year boat with all the latest CG, EPA, SOLAS regulations, etc installed), or build a 60-year ferry that will need modifications as she ages?

This is primarily a question of economics. For vessels engaged in trans-ocean shipping such as bulk carriers or tankers, an owner typically will construct a vessel with a nominal 25 to 30-year life. At the end of 15 years, when the maintenance issues begin to become more significant, the first owner will generally sell the vessel into a vigorous second hand market. The second owners typically operate in trades with lower margins, so they are willing to have a reduced capital cost and to accept the higher degree of maintenance that may be required. They, in turn, may sell the vessel again to an operator who will keep the vessel going until it is scrapped.

This same scenario is played out in the international ferry market as vessels initially constructed for the North Sea routes then get sold to Mediterranean ferry operators who in turn sell the vessels to operators in Asia. This happens because the ferries are constructed to international standards and are not subject to cabotage restrictions such as the U.S. Jones Act or the Passenger Vessel Services Act.

In the U.S., the ferries are often built for very specific route with often unique terminal interfaces. There is little market for second-hand tonnage among domestic operators so for vessel disposition, the Owner has to look to the international market. This will likely bring lower prices compared to foreign tonnage since U.S. built ferries are not typically constructed to international standards, such as the Safety of Life at Sea Convention (SOLAS), and thus will require modification by a foreign buyer. Consequently, most U.S. ferry operators tend to hold onto their vessels until they are obsolete due to changing route demands or to regulatory obsolescence. They cannot count on selling the vessel to a market where there is demand, so it makes sense to operate, and depreciate, the vessels until only scrap value remains.

SOLAS standards are intended for vessels engaged on international voyages. As such, they have additional requirements for life-saving equipment, structural fire protection, damaged stability, and safety systems. Most countries do not require their smaller domestic vessels to comply with SOLAS. Canada is an exception. Constructing the smaller ferries to SOLAS standards would likely add 10% to 15% to the capital cost of the vessels. The U.S. Coast Guard clearly believes that the domestic regulations provide an adequate level of safety for vessels operating within our territorial waters. This is borne out by the excellent safety record for the passenger vessel fleet. Being constructed to SOLAS standards does not make the vessel more robust or result in an extended service life. It does mean increased maintenance costs due to the additional features and systems installed.

I believe that the AMHS philosophy of a 50 to 60-year design life for their vessels makes sense. A private operator is allowed to depreciate the value of their capital assets and take advantage of reduced taxes. This does not apply to government organizations, so there is a life cycle cost benefit to holding on to an asset. A nominal 50-year life allows a major re-engining at 25 to 30 years and interior refurbishments every 15 to 20 years. The downside of this approach is the large capital cost of replacing vessels and the periodic investments to refurbish them. I would certainly advocate some sort of construction reserve fund be adopted by the Alaska legislature to build the capital account over time, rather than subject the ferry system to the changing politics of transportation priorities. The AMHS should also invest additional funds during the initial construction to ensure that the materials used in construction reflect the expected life span of the vessel. This particularly applies to the initial coasting systems and the choice of piping materials.

It should be noted that the Inter-Island Ferry Authority faced these same issues when they designed and built their first vessel. Since they had a very restricted capital budget, they were not able to invest in "top of the line" equipment and materials. The vessel's structure was designed to meet the ABS Rules for Building and Classing Steel Vessels of Under 90m in Length so the scantlings are adequate if the coating systems are maintained. Some of the piping systems use steel pipe in lieu of copper-nickel (Cu-Ni) so they may require replacement in 25 years. There is no reason why the IFA vessels, with proper maintenance and periodic upgrades, cannot achieve a service life of 50 plus years.

<u>Vessel/Route Optimization</u>

Is it better to provide two smaller boats on a run to provide greater service (frequency) or one larger, more "capable" ferry making one run?

In general, it is always better to have two smaller vessels on a single route. Not only is there a greater service frequency, but there is at least some level of service if one vessel is out for maintenance or repair. Another benefit of two vessels is the ability to tailor service to seasonal ridership by putting one vessel into layup. The increase in manning costs with two smaller vessels (Sub K or equivalent) versus one larger Sub H vessel may be quite small. Further, there is a potential safety aspect, at least on short runs, where one vessel can come to the assistance of the other. The drawbacks of two vessels versus one are greater capital cost, increased crewing cost, lower energy efficiency, more subject to weather disruptions or delays, and challenges in handling larger vehicles. A single, larger vessel will be capable of greater speed and can provide more spacious accommodations for both passengers and crew. The larger vessel may also be more flexible in serving other AMHS routes as needed to support system priorities.

<u>Process to Develop an Optimal Design (Design Process)</u>

The process to develop an optimal design begins with a clear set of Owner's requirements. This document is typically developed through collaboration between the operator and the designer. For a given route, the traffic volume is defined (numbers and types of vehicles with seasonal variations) along with service expectations (frequency and duration of trips). These two factors (capacity and speed) establish the minimum vessel size for the route. Other factors such as passenger comfort, passenger amenities, terminal interface, and safety standards may increase the size from the minimum requirements.

In addition to the basic operation of the vessel, the Owner's requirements should establish standards or aspirations for energy efficiency, redundancy, maintenance, crew accommodations, environmental condition (temperatures, vibration levels, noise, motions, and emissions). It should also define expectations for future events such as life cycle weight growth, ability to stretch the hull to handle increased capacity, or adaptability to new technology such as engine emissions controls.

Once the Owner's requirements have been established, the concept design or design study report (DSR) phase begins. In this phase, the ship designer should experiment with different concepts of arrangements such as side loading versus end loading, enclosed vehicle deck versus open deck with high bulwarks, and the mix of enclosed passenger spaces and open deck areas. It has been said that 80% of the cost of a vessel is established in the early stages of the design process, so it is important to be creative while still paying attention to regulatory requirements and physical constraints. This phase is also the place to investigate new technologies that might be incorporated into the design. For instance, the operator may wish to provide for the future installation of a diesel engine exhaust treatment system to meet the proposed EPA Tier 4 emissions requirement. A study of treatment technologies and their impact on space and weight could be part of the DSR phase.

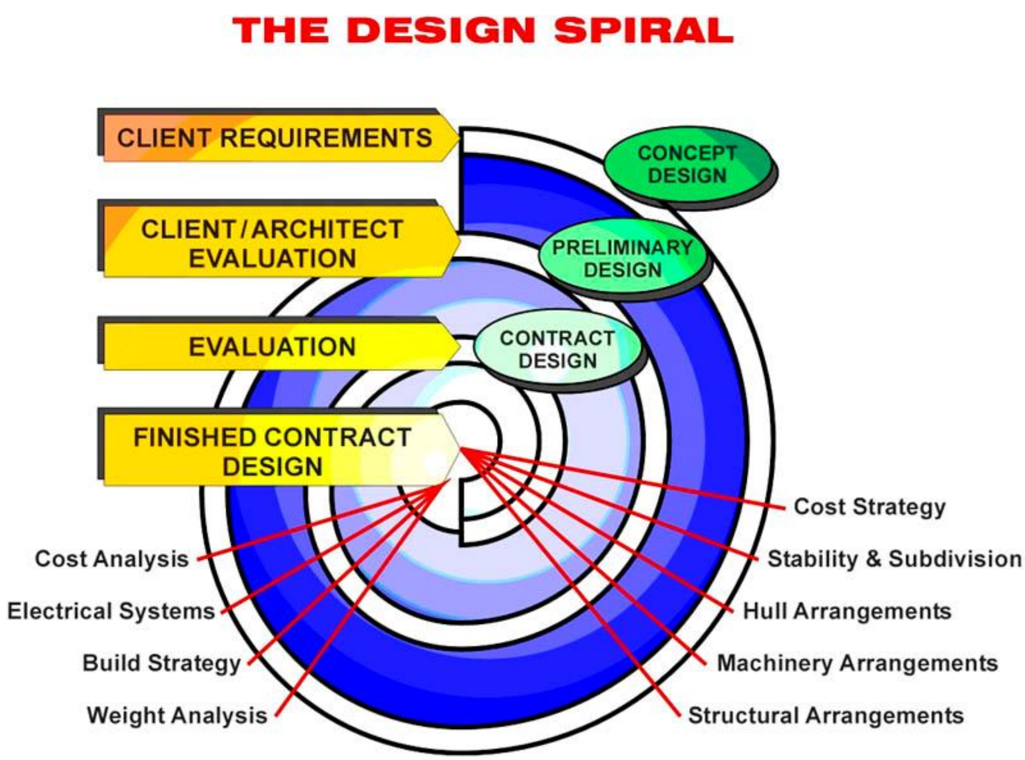
Another key topic to consider in the DSR phase is how the Owner intends to contract for the vessel. The Alaska Marine Highway System has used a variety of different contracting approaches in the past. The Fast Vehicle Ferries were procured using a design/build method where the Owner established an extensive set of performance criteria as the basis for the contract. The shipyard then proposed a design and construction approach to meet those performance standards. A more traditional method is for the Owner's naval architect to develop a technical package that explicitly defines the vessel and its systems. This package is then used by the shipyards to prepare their bids and is used by the Owner to verify that the selected shipyard is complying with the contract. Beyond these two approaches, there are a variety of different contracting methods that have been tried for ferry procurement. The Owner should carefully consider which contracting approach will best control risk and deliver a satisfactory vessel. Factors to consider are the type of ferry, the complexity of its systems, and the skills of the potential shipyards.

Concurrent with the DSR effort, the operator should initiate the public process effort. The goals of this effort are to identify key stakeholders (both public and private), to inform them as to the need for the project, and to present a process for stakeholder input. With the fierce competition for public funds and the high degree of environmental scrutiny, any ferry project needs to embrace the public process.

At the end of the DSR phase, the design team and the operator should re-visit the Owner's requirements to see if any of them are overly constraining or are adding unnecessary expense. For example, bow loading may save some operating time but may add significant expense to the terminal design and to the vessel capital cost. This is also a critical point for an outside review or value engineering study, which may identify opportunities for the designer and operator to consider.

The next phase of the vessel design process is to prepare plans, specifications and estimates (PS&E). For a new vessel this will generally require three steps. The first is to prepare a revised set of Owner's requirements, based on the results of the DSR, the Value Engineering effort, and the Public Process. The next step is to develop a preliminary design based on those requirements to confirm basic assumptions of speed and power, electrical capacity, passenger amenities, weights and stability, and functional relationships of areas and volumes. As a graphic of the process, the Evans Design Spiral (below) shows the subject areas that need to be addressed as a design is developed. Note that the process is structured to provide opportunities formal evaluation of the design by the client (Owner) as the design matures.

The third step of the PS&E phase is to prepare the contract design that will be used to bid the project. The extent of the contract design package should be determined during the DSR phase when the procurement strategy is established. Regardless of the contracting method selected by the Owner, the bid package must contain some degree of technical content by which the Owner can measure the success of the ferry procurement.



<u>Studies Recommended by EBDG to Reduce Costs</u>

In addition to the typical design process presented above, the following studies should be considered as measures to reduce capital and operational costs.

- Perform a traffic study to determine the minimum vessel sizes and speeds required for each route.

- Perform a manning study to determine potential reductions crew size. Crew size may be reduced by reducing the number of survival craft or installing machinery automation.

- Perform a propulsion study to determine the optimum engine installation. Typically, conventional propulsion is the most inexpensive and should be used when other requirements do not necessitate a more complex installation. Also, consider that domestic brands are less expensive to maintain and quicker to repair due to availability of replacement parts and local repair professionals.

- Perform a passenger loading study to determine if passenger loading ramps are feasible and cost effective due to reduction of crew hours, or desirable to improve schedule keeping. Based on the number of passengers, it can then be determined if the passenger load time is the limiting factor on overall load time, and if there is possible additional benefit to be gained from installation of a bow door for vehicle loading.

REFERENCES

1. AMHS Vessel Suitability Study, Task 1 Report, The Glosten Associates, Inc., March 23, 2000.
2. Shore Protection Manual 1984, Coastal Engineering Research Center, US Army Corps of Engineers, 1984.
3. Southern Gateway Feasibility Study, The Glosten Associates, Inc., May 16, 2005.
4. Index of Estimated U.S. Shipbuilding Costs, http://shipbuildinghistory.com/today/statistics/, 09/16/2009.
5. Producer Price Index for self propelled ships, new, nonmilitary, http://data.bls.gov/PDQ/outside.jsp?survey=wp, Bureau of Labor and Statistics, 09/16/2009.
6. ALASKA CLASS FERRY, Route Timing Calculations, 06137.04-01M, 02/27/2009.
7. Alaska Class Ferry Preliminary Design, EBDG Job 06137, 2009.
8. Operating Cost Estimate, Email from Robert Ekse, ADOT&PF, September 24, 2009.
9. IFA Ferry Costs, Email from Roberta Landgren, Inter Island Ferry, September 16, 2009.
10. AMHS Annual Financial Report – 2005, AMHS ADOT&PF, June 30, 2005.
11. Class Cost Factors, 09086-001-043-1, Rev -, EBDG, September 30, 2009.
12. AMHS Vessel Suitability Study, Task 1 Report, The Glosten Associates, Inc., March 23, 2000.
13. USACE Shore Protection Manual, 1977.

Appendix A

SMP Seakeeping Analysis for Planning Factors

Purpose

This appendix describes the procedure used to calculate seakeeping responses using the SMP program. SMP, "Ship Motion Program," is developed by the David W Taylor Naval Ship R&D Center. The 1993 version of SMP is used for this analysis.

Procedure

Geometry Development

SMP is a strip theory seakeeping program, which means that the geometry input is a series of stations which define strip surfaces used in the calculations. Twenty stations are input to define the hull shape. Additionally, appendages are defined as members with added mass and damping coefficients.

Vessel centers of gravity are taken from previous stability models at fully loaded conditions. The vessel gyradii are estimated using parametric values of ratios gyradii to their associated principle dimension. For example, the gyradius in roll is a function of the overall beam of a vessel. All four vessels were given a roll gyradius of 40% beam, a pitch gyradius of 25% of LOA, and a yaw gyradius of 25% of LOA.

RAO Values

The program calculates the Response Amplitude Operator (RAO) values from the input vessel geometry. RAO values describe the unit response in 6 degrees of freedom as a function of encounter frequency. RAO tables can be used to determine if there are any resonant frequencies in pitch, roll, or heave. These frequencies show up as spikes in the data and can adversely affect the statistical responses of the vessel, especially if they are near the peak of the energy of the sea spectrum.

Sea Conditions

All cases are run with a Bretschneider sea spectrum. In order to facilitate iteration of the results for different significant wave heights, all significant wave heights are entered as 1.0 and the responses are assumed to be linear. This means that all of the output responses can be multiplied by the actual significant wave height to calculate the actual responses. The program automatically chooses a range of peak frequencies that will be used in the calculation later. See below for a description of how the correct peak frequency is chosen.

Responses

Statistical responses are derived by first multiplying the RAO values by the sea spectrum. This gives response spectra at 6 degrees of freedom and at multiple peak frequencies. The response spectra give actual response values at each wave encounter frequency.

Because the program gives multiple response spectra plots at different peak frequencies, the appropriate peak frequency must be determined. The peak frequency is calculated using methods from the Shore Protection Manual (SPM), which can be used to find peak frequency at the correct significant wave height. The response spectra with the peak frequency closest to this calculated peak frequency, gives the statistical responses of the vessel.

Results

The program outputs the significant vertical accelerations at a worst-case point of interest. This value is converted to RMS vertical acceleration for comparison with the Motion Sickness Index (MSI) which can be found in PNA Volume III. Firstly, the MSI value is found for the 99% case for all vessels. The MSI value for each vessel is compared and each vessel is assigned a rank. Secondly, the maximum sea state which does not exceed the lowest MSI value is iteratively found.

Conclusions

Conclusions are described in Task 3 above. Some concerns with the results which may affect conclusions are presented here.

The IFA ferry and the BARTLETT are both very similar in size and hull form. It is surprising that the vertical accelerations given by the program are much different from each other. When one compares the vessels motions, it can be seen that they are not very much different. This suggests the possibility that one of these vessels should be outputting different acceleration results. Compared to the other vessels, the IFA results are the most extreme, so it seems more likely that these are in error and should be closer to the values output for the BARTLETT.

Appendix B

AURORA and LITUYA Operating Costs

IFA Ferry Operating Costs

Fuel vs. Personnel Cost for Incremental Speed Change

AURORA AND LITUYA OPERATING COSTS

Aurora

2009	Cost (x1000)	weeks	/yr = 46 wks	inflation index	Cost (x1000) 2009
Fuel	$ 2,619	47.3	2547	1.00	$ 2,547
Personnel	$ 3,990	47.3	3880	1.00	$ 3,880
Commodoties	$ 502	47.3	488	1.00	$ 488
Overhaul (materials&labor)	$ 696	4.9	994	1.00	$ 994
Indirect	$ 1,835	47.3	1785	1.00	$ 1,785
Sum			9694		$ 9,694
2008					
Fuel	$ 665	15.1	2026	1.38	$ 2,796
Personnel	$ 1,630	15.1	4966	0.96	$ 4,762
Commodoties	$ 179	15.1	545	0.90	$ 492
Overhaul (materials&labor)	$ 857	7.9	759	0.97	$ 739
Indirect	$ 902	15.1	2748	0.90	$ 2,481
Sum			11044		$ 11,271
2007					
Fuel	$ 1,771	45.1	1806	1.50	$ 2,706
Personnel	$ 3,705	45.1	3779	0.95	$ 3,603
Commodoties	$ 454	45.1	463	0.99	$ 459
Overhaul (materials&labor)	$ 1,158	7	1158	1.01	$ 1,166
Indirect	$ 1,665	45.1	1698	0.99	$ 1,684
Sum			8905		$ 9,619
Averages					
Fuel					$ 2,683
Personnel					$ 4,082
Commodoties					$ 480
Overhaul (materials&labor)					$ 966
Indirect					$ 1,983
Sum					**$ 10,195**

Lituya

2009	Cost (x1000)	weeks	/yr = 51 wks	inflation index	Cost (x1000) 2009
Fuel	$ 211	46	234	1.00	$ 234
Personnel	$ 752	46	834	1.00	$ 834
Commodoties	$ 63	46	70	1.00	$ 70
Overhaul	$ 197	6.1	89	1.00	$ 89
Indirect	$ 309	46	343	1.00	$ 343
Sum	$ 309				$ 1,569
2008					
Fuel	$ 302	51	302	1.38	$ 417
Personnel	$ 832	51	832	0.96	$ 798
Commodoties	$ 18	51	18	0.90	$ 16
Overhaul	$ 90	0.9	275	0.97	$ 268
Indirect	$ 306	51	306	0.90	$ 276
Sum					$ 1,775
2007					
Fuel	$ 240	50.8	241	1.50	$ 361
Personnel	$ 701	50.8	704	0.95	$ 671
Commodoties	$ 26	50.8	26	0.99	$ 26
Overhaul	$ 19	1.3	40	1.01	$ 40
Indirect	$ 265	50.8	266	0.99	$ 264
Sum					$ 1,362
Averages					
Fuel					$ 337
Personnel					$ 768
Commodoties					$ 37
Overhaul					$ 132
Indirect					$ 294
Sum					**$ 1,569**

IFA FERRY OPERATING COSTS

IFA FERRY

Program Expenses	2004 $	2009 $		Program Expenses	2005 $	2009 $		Program Expenses	2006 $	2009 $	
Operations Expenses				**Operations Expenses**				**Operations Expenses**			
Vessel Ops: Fuel	413,452.50	614,414.72	29%	Vessel Ops: Fuel	524,967.09	526,301.53	24%	Vessel Ops: Fuel	656,480.48	531,000.62	23%
Vessel: Security	2,851.25	3,293.12		Vessel: Security	2,344.44	2,622.63		Vessel: Security	1,304.93	1,416.67	
Safety Training	1,143.22	1,320.39		Adv Fire Safety Training	9,341.00	10,449.41		Safety Training	1,020.80	1,108.21	
Uniforms	3,494.04	4,133.83		Uniforms	2,803.33	3,114.61		Uniforms	3,152.31	3,287.49	
Vessel Ops: Crew Meal Vouchers	$16,258.23	19,235.24		Vessel Ops: Crew Meal Vouchers	$16,205.60	18,005.08		Vessel Ops: Crew Meal Vouchers	$16,309.21	17,008.59	
Vessel Ops:Stores & Supplies	9,591.17	11,347.39		Vessel Ops:Stores & Supplies	8,986.91	9,984.82		Vessel Ops:Stores & Supplies	11,019.89	11,492.45	
Vessel Ops:Oil, Filters, & Related	2,848.87	3,370.52		Vessel Ops:Oil, Filters, & Related	17,555.92	19,505.34		Vessel Ops.Oil, Filters, & Related	12,782.90	13,331.06	
Vessel Ops:Vessel Waste	6,180.89	7,312.66		Vessel Ops:Vessel Waste	6,461.80	7,179.32		Vessel Ops:Vessel Waste	5,840.14	6,090.58	
Vessel Ops: Hol Land Line	227	268.57		Vessel Ops: Hol Land Line	668.84	743.11		Vessel Ops: Hol Land Line	767.76	800.68	
		0.00		Vessel Ops: Cell Phones	4,130.29	4,588.92		Vessel Ops: Cell Phones	3,518.28	3,669.15	
		0.00		Vessel Ops:Laundry	22.13	24.59		Vessel Ops:Laundry	45.95	47.92	
		0.00		Vessel Ops: Vehicle Damage	54.25	60.27					
		0.00						Vessel Ops:Licensing & Inspections	335	349.37	
Total Operations Expenses	**$456,047.17**	**$664,696.44**	**31%**	**Total Operations Expenses**	**$593,541.60**	**$602,579.64**	**28%**	**Total Operations Expenses**	**$712,577.65**	**$589,602.80**	**26%**
Personnel Expenses				**Personnel Expenses**				**Personnel Expenses**			
Personnel:Payroli	672,136.04	776,299.53		Personnel:Payroll	706,038.84	789,818.30		Personnel:Payroll	715,076.60	776,308.55	
Personnel:Payroli Taxes	57,548.02	66,466.46		Personnel:Payroll Taxes	62,371.68	69,772.78		Personnel:Payroll Taxes	44,991.89	48,844.54	
Personnel:Drug Screening	1,340.00	1,547.66		Personnel:Drug Screening	1,600.00	1,789.86		Personnel:Drug Screening	1,330.00	1,443.89	
Personnel:Employee Hlth	64,596.25	74,606.98		Personnel:Employee Hlth	59,154.79	66,174.17		Personnel:Employee Hlth	72,661.32	78,883.30	
Personnel:Employee Life	550.8	636.16		Personnel:Employee Life	559.4	625.78		Personnel:Employee Life	602.83	654.45	
Personnel:PERS	31,118.51	35,941.06		Personnel:PERS	59,287.42	66,322.54		Personnel:PERS	86,864.95	94,303.19	
								Personnel:AK SBS	23,937.91	25,987.71	
Total Personnel Expenses	**$827,289.62**	**$955,497.85**	**45%**	**Total Personnel Expenses**	**$889,012.13**	**$994,503.43**	**46%**	**Total Personnel Expenses**	**$945,465.50**	**$1,026,425.64**	**45%**
Maintenance Expenses				**Maintenance Expenses**				**Maintenance Expenses**			
Vessel Maintenance:Misc.	145,857.68	156,838.78		Vessel Maintenance:Misc.	31,222.44	33,573.07		Vessel Maintenance:Misc.	56,208.41	60,440.14	
				Vessel Maintenance:Spares	2,374.11	2,552.85		Vessel Maintenance:Spares	13,495.25	14,511.26	
				Vessel Maintenance:Annual	33,214.38	35,714.97		Vessel Maintenance:Annual	145,116.47	156,041.77	
				Vessel Maintenance:Main Engs & Gens	78,190.89	84,077.60		Vessel Maintenance:Main Engs & Gens	869.7	935.18	
Total Maintenance Expenses	**$145,857.68**	**$156,838.78**	**7%**	**Total Maintenance Expenses**	**$145,001.82**	**$155,918.49**	**7%**	**Total Maintenance Expenses**	**$215,689.83**	**$231,928.34**	**10%**
Miscellaneous Expenses				**Miscellaneous Expenses**				**Miscellaneous Expenses**			
Insurance:Ocean Marine	286,710.13	339,209.08	16%	Insurance:Ocean Marine	245,167.65	272,391.22	13%	Insurance:Ocean Marine	310,690.80	324,014.05	14%
Autos:Gas	1,145.52	1,355.27		Autos:Gas	950.5	1,056.04		Autos:Gas	1,268.88	1,323.29	
Autos:lnsurance	2,557.20	3,025.44		Autos:lnsurance	3,335.36	3,705.72		Autos:lnsurance	3,927.82	4,096.26	
Autos:Licensing	646	764.29						Autos:Licensing	268	279.49	
Autos:Other	167.95	198.70						Autos:Other	62.82	65.51	
Tools Grant	66.35	78.50									
				Safety Equipment Grant	17,817.51	19,795.98					
				Hollis Security Grant Exp	104,901.17	116,549.46		Hollis Security Grant Exp	60,266.50	62,850.89	
								POW Construction	4,507.74	4,701.04	
								Ktn/Hol Vessel Capital Project	19,072.00	19,889.86	
Total Miscellaneous Expenses	**$291,293.15**	**$344,631.29**	**16%**	**Total Miscellaneous Expenses**	**$372,172.19**	**$413,498.42**	**19%**	**Total Miscellaneous Expenses**	**$400,064.56**	**$417,220.40**	**18%**
Total Program Expenses	**$1,720,488**	**$2,121,664.36**		**Total Program Expenses**	**$1,999,728**	**$2,166,500**		**Total Program Expenses**	**$2,273,798**	**$2,265,177.18**	

FUEL VS. PERSONNEL COST FOR INCREMENTAL SPEED CHANGE

Below is a table showing the net dollars saved at each speed against the next higher speed. Fuel reduction percentages are based on a 5,000 BHP EMD engine for the Alaska Class Ferry. Dollars are expressed in thousands of dollars per year, with negative values indicating a yearly reduction in expenses. The highlighted range of speeds encompasses the estimated range of speeds for the potential class design. The d$ total column indicates that, for example, running at 10 knots costs $80k less than 12 knots; running at 12 knots is $41k less than 13 knots, etc. Values are in thousands of dollars, and negative values indicate a savings in cost per year for the given speed increments. These results are specific to the assumed vessel type, engine type, route length, and number of crew, however, the method can easily be adapted to other vessels when the data on that vessel is available.

5000 BHP engine in SS4		running hrs/day		6.00						
		idle hrs/day (assume)		4.00						
V (kts)	PB/prop	fuel%/hr	hr %	fuel %	$/yr fuel	d$ fuel	wage %	$/yr wage	d$ wage	d$ total
10	1874	-31%	120%	-26%	614	-157.4	10%	776	77.6	-80
12	2592	-14%	108%	-13%	614	-77.1	5%	776	35.8	-41
13	3032	-14%	108%	-13%	614	-78.8	4%	776	33.3	-46
14	3537	-17%	107%	-16%	614	-95.3	4%	776	31.0	-64
15	4125	-14%	107%	-13%	614	-82.6	4%	776	29.1	-54
16	4824	-15%	106%	-14%	614	-84.9	4%	776	27.4	-57
17	5628	-14%	106%	-14%	614	-83.9	3%	776	25.9	-58
18	6498	-18%	106%	-17%	614	-106.0	3%	776	24.5	-81
19	7682	-20%	105%	-19%	614	-117.5	3%	776	23.3	-94

fuel%/hr – The reduction in fuel consumption per hour at the given speed vs. the next higher speed.

hr% − The total number of hours required at the given speed vs. the next higher speed required to complete a given route.

fuel% − The reduction in fuel consumption on a given route vs. the next higher speed.

$/yr fuel – Estimated dollars (thousands) spent on fuel per year. Arbitrary value used for comparison between two speeds.

d$ fuel – Change in fuel cost per year vs. next higher speed.

wage % − The increase in wage hours per year at the given speed vs. the next higher speed.

$/yr wage – Estimated dollars (thousands) spent on crew costs per year. Arbitrary value used for comparison between two speeds.

d$ wage – Change in wage cost per year vs. next higher speed.

d$ total – Net change in operating cost at given speed vs. next higher speed.