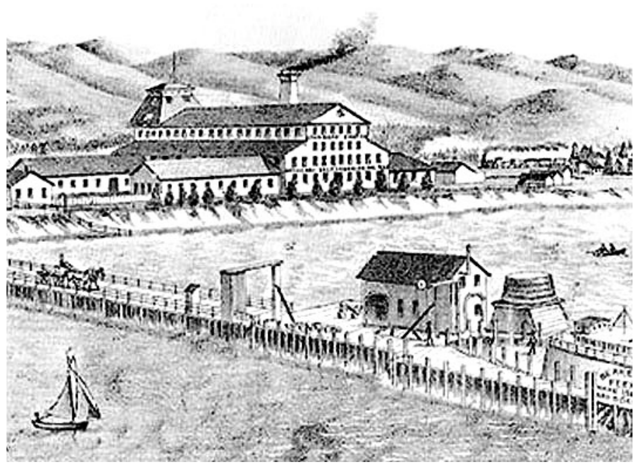
Urban Passenger-Only Ferry Systems: Issues, Opportunities and Technologies

Paul Kamen, N.A.[1]
Christopher D. Barry, P.E.[2]



Jacobs Wharf Ferry Terminal, Berkeley California, c. 1880

Abstract:

Increasing traffic load and urban sprawl has created a call for new passenger only ferry systems in a number of urban areas, notably San Francisco. Urban ferry systems have traditionally been favored by environmental advocacy organizations and progressive land use and transportation planners. Ferry systems can offer a wide range of benefits… However, recent proposals have encountered unanticipated opposition based on perceived problems in these areas. There are also new technologies and other changes that may offer new opportunities and challenges. As a result, modern trends in speeds, propulsion systems and layout of both vessels and terminals may change significantly with the next generation of ferries. Primarily examining the San Francisco Bay Area as a case history in progress, the authors examine how these developments and new concepts of public transit efficiency, emissions, land use and system integration play key roles in the political viability of new ferry service, and how these considerations ultimately reflect back on the vessels themselves by imposing new sets of design constraints. Some short-term solutions are proposed, and long-term predictions for the shape of the mid-21st Century urban ferry are presented

Issues

Naval architects designing ferries must contend with optimization of a complete system, not just a vessel, especially in the very early stages when initial vessel requirements are set. In many cases, changing non-marine aspects of the system may solve difficult ship design problem by eliminating the need for a requirement. The design of a ferry system as a whole is essentially a classical design spiral surrounding the traditional ship design spiral. In other cases, naval architects are part of the team making the case for or against a whole system, and need to be cognizant of the impacts and effects of the entire system.

We are seeing more and more ferry systems and proposals for ferry systems in urban areas, but why use a ferry to

[1] Principal, Surface Propulsion Analysis; Commissioner, Berkeley Waterfront Commission
[2] Senior Naval Architect, U.S, Coast Guard Engineering Logistics Center

span a body of water that is already crisscrossed by bridges and tunnels? Some ferry advocates claim that new technologies have made high speed ferries viable, and though true this really is a limited improvement. Wheels on steel rails or smooth concrete still produce negligible resistance compared to the frictional and wave-making effects of a hull in water. And land vehicles enjoy essentially 100% propulsive efficiency between driveline and useful thrust. Public land vehicles also benefit from an economy of scale: A single operator can drive a train that moves well over a thousand commuters, or a bendy bus or multi-car streetcar holding a hundred or more passengers.

Land-based transit can serve multiple terminals within the high-density centers of business, commercial and residential districts. A single commuter lane typically carries 2,000 people per hour. Change to bus / HOV status, and this increases to 24,000 people per hour. Yet this remains an unfeasible solution for increasing capacity in many areas for a variety of reasons. The most important issue is that past patterns of residential development have created sprawl that limits the penetration of mass transit. The existing infrastructure to support this development is also optimized for automobiles. This means that automobiles will retain substantial advantages over mass transit. Unfortunately, the limited available rights of way for bridges, tunnels, and freeways, and the huge investment required to expand them has created choke points that ferries can relieve.

Ferries require much less infrastructure investment, have flexible routing topology as demand patterns change over time and near infinite scalability. Though it could be argued that the opportunities of urban ferries represents a profound failure of transit and land use planning and politics and an irrational approach to increasing mobility, we design for the world as it is, and not for world as it should be. Ferries will not reduce congestion or improve air quality and mobility as much as "more rational" approaches to better use of the existing infrastructure, but the more rational approaches simply aren't really feasible. Also, ferries enjoy one correspondingly irrational advantage over other transit modes: People like boat rides. There is an attraction to the water that is deeply rooted in the human psyche. The big secret is that the pay-off of ferries is not cleaner air, reduced congestion, greater mobility or shorter commute times. The real justification for the urban ferry, aside from increasing job opportunities for naval architects and shipyards, is quality of life.

Environmental

"It's not easy being green"

Kermit the Frog

Ferry systems proposed in the San Francisco Bay Area and running in New York have come under fire from environmental advocates because they may not, as claimed, significantly reduce air pollution. Though some of the claims of environmentalists were ill-founded and erroneous, they probably are correct in believing that at best, ferries will not add to the existing air pollution load. Other environmental effects, notably wake wash, are manageable if the system is well implemented, and the current proposals are being carefully watched to ensure that they meet this standard.

The main potential environmental impacts of ferries are air pollution due to engine emissions, wake, water pollution from bottom paint and ship discharge systems, and loss of waterfront, noise, and effects on growth, particularly locally to the terminal. There are also minor potential effects from industrial activities to maintain the vessels, but these can be mitigated by current practices. It is important to note that the effects (except for wake) may not be entirely, or even mostly, due to the vessel itself. The intermodal connections may cause environmental impacts as well, especially if large numbers of automobiles are involved. It is in the mitigation of environmental effects that new technology and other systems have the most potential to make a ferry system the best possible ecological choice.

First, it is important to remember that minimizing or even evaluating environmental impacts is rarely as simple as it seems. A good example is use of "biodiesel", which is derived from plant oils, usually soybeans. Though there are good reasons that biodiesel might reduce air pollution and green house gases, extensive use of biodiesel will require increased farming of oil seed crops, which has environmental impacts of its own, most notably increased water pollution. Though soybeans are nitrogen fixing, they still require phosphate fertilizers, which run off and increase nutrient loads in rivers and estuaries. The increased mass of agricultural waste (soybean, field waste traditionally, is plowed under to add nitrogen for a successive non-legume crop) may also produce greenhouse effects: Rotting vegetation produces methane, which has twenty times the greenhouse effect of carbon dioxide. Economic input (money for fuels going to farmers instead of foreign oil producers) may also have environmental effects. Extensive use of biodiesel may require further remediation measures, such as collection and utilization of agricultural waste, growing filtering species such as switchgrass in agricultural runoff areas or artificial aeration of rivers or estuaries. Each of these technologies has impacts and opportunities as well: Switchgrass has been proposed as a feedstock for other biological fuels (Blankenship, 2001).

Air quality issues are an important part of the environmental impact of ferries. There have been four major reports on the impact of ferries on air pollution. The first report by Long (1999) oversimplified the analysis, "spun" some data, neglected critical information and thus greatly overestimated the relative air pollution produced by ferries as opposed to automobiles and buses.

Sweeney (2000) has offered a rebutting analysis that suggests ferry transit produces less air pollution than auto traffic, though perhaps slightly more than bus traffic. The San Francisco Bay Area Water Transit Authority (WTA) (2002) has done an Environmental Impact Report (EIR) of its own, and CALSTART (2002) has analyzed three routes in San Francisco and provides a very thorough and substantive report. Corbett, et al (Corbett, 2003) have done an analysis of the impact of ferries on New York City air quality.

The WTA EIR and CALSTART studies suggest that given substantial additional, but feasible, controls to eliminate pollutants, ferries can improve or nearly equal air quality compared to automobiles for most routes. (The longest, fastest route is the most problematic in the CALSTART study, and is not shown to have lower emissions.) The best technology proposed is EPA Tier 2 (off-road engine requirements beginning in 2007) with the use of Selective Catalytic Reduction (SCR) of NO_x and catalyst filters for diesel particulates. (SCR uses ammonia or urea over a catalyst bed to reduce NO_x to nitrogen and oxygen.) Though these technologies are commercially available and in use for stationary engines, and have been demonstrated on large marine diesels and European ferries, they will require on-board reagent storage and increased space and weight claim for the systems, and of course, increased capital and operating cost.

The Corbett study is more pessimistic, suggesting that ferries will require more reduction than is possible with currently available technology to compete with autos or other modes on an air quality basis in New York City.

All of these studies have many assumptions that can be questioned, (though the magnitude of the numbers is sobering and a call to action). They include significant loads from the landside emissions associated with travel to and from the terminals, which are based on assumptions on mode of travel and distance to the terminal. Induced demand is presumed to reduce the beneficial effect of getting riders out of cars, and the magnitude of this effect is subject to substantial question. The studies also use a fairly high level of vessel speed in some cases, which might not be appropriate for future service. The pollution potential of comparative modes of transport are also worth questioning; the studies are mainly based on the presumed 2007 automobile fleet.

The CALSTART study also includes numerous suggestions for improving the air quality impact of ferry systems, and it is worth noting that many of them address the most obvious issue: The amount of pollution a ferry produces doesn't change with passenger load, so filling the ferry is the best option for reducing pollution per passenger mile – the CALSTART study assumes 15% to 33% daily occupancy. One important issue is to fill the boat on the back haul. An empty car doesn't make a return voyage, but an empty ferry might. In some areas, the smaller number of reverse commuters is more likely to travel alone, as they have less traffic to contend with, so getting them out of their cars has a proportionately larger effect on air quality. Thus strategies to increase the use of ferries for the reverse commute such as preferential pricing might benefit air quality. Other suggestions include actions to reduce the air quality impact of travel to and from the terminal.

The WTA EIR also addresses energy use. Energy use is also effectively a proxy for greenhouse gas emissions, since most fuels emit carbon dioxide pretty much proportionately to their energy content. The CALSTART report addresses CO2 emissions directly. The WTA EIR estimates that ferries require 4,360 BTU/Passenger miles vice 4,342 for the auto/rail/bus combination that would result from no additional ferries. This is pretty much a push considering the imprecision of the basic assumptions, and it is easy to see that some changes may radically improve the energy efficiency of ferries, and thus lower their greenhouse gas impact. Ferries on some routes are better from a viewpoint of global warming. The CALSTART report finds that Tier 2 engines alone, or in combination with technologies that do not lower engine temperatures to control NOx formation (such as SCR) provide the most reduction of CO2. Thus there is even a trade-off between greenhouse effect and the adverse effects of the other pollutants.

Dredging is another environmental impact, and in some harbors, the disposal of dredge spoils is a significant problem, because they are polluted with heavy metals or other toxic materials. Here the key is to design boats and select sites for minimal dredging.

Anti-fouling paints, and to a much lesser extent topside paints, also have environmental impacts. Low VOC paints are rapidly being developed that provide good protection and appearance without air quality issues, and aluminum can be left bare. Applied thin film appliques also provide excellent cosmetics and protection at relatively low labor costs. The Coast Guard is no longer painting their 41-foot utility boat topsides, and the production 47-foot motor lifeboat topsides were never painted. Instead, a glass bead finish process has been developed (Coast Guard, 2006) to provide an acceptable appearance with the requirement for cosmetic painting. Tributyl tin bearing anti-fouling paints are being phased out and are being replaced by non-toxic low surface energy slick coatings. These paints self clean by the effect of the boat's motion through the water. These coatings require that the boat be relatively fast and operated frequently, which is certainly an acceptable requirement for a ferry.

A certain amount of waterfront loss is inevitable for a ferry terminal, but this too can be minimized. Likewise, good strategies for effective intermodal connections can minimize local effects, and the whole point of a ferry is to minimize regional effects. One strategy for minimizing perceived waterfront loss is to use mainly floating terminals. The Sea Bus system in Vancouver's Burrard Inlet uses entirely floating facilities made of concrete, though in this case to deal with a 17-foot tidal range. However, the terminals are expected to have at least a 50-year life, Case (1981). Terminals in sensitive areas could also be placed well away from shore, connected by floating or cable suspended walkways.

An even more interesting (though perhaps extreme) possibility for mitigating the impact of both terminals and wake is a revival of the oldest ferry technology: The terminal itself could move out to the ferry by hauling itself on an underwater cable.

Even accurately evaluating, much less minimizing, environmental impact requires careful evaluation, with great potential for surprises and surprising opportunities for improvements. Good science is important and flawed environmental science is harmful in a similar fashion to medical quackery; both delay appropriate treatment and allow the patient to be harmed meanwhile. Regardless of any possible flaws in the pessimistic studies, though, it has had an effect of bringing the marine industry to "flank bell" with regard to alternative propulsion and other measures to minimize air pollution, so it is not a total loss. A ferry system may also be an opportunity for encouraging other changes in transit preferences based on pricing or terminal parking policies.

Wake wash is another environmental issue that requires careful evaluation. Most of the major impacts (literally) of wake wash have been seen in Europe, where a fast ferry might be a 100 meter long vessel with several hundred passengers and a couple of hundred cars and trucks, doing 36 knots. This is a very different creature than most of the commonly proposed commuter ferries, but large fast auto carrying ferries might have significant issues with wake. The wake sensitivity of an area also varies along the routes. Blume (2001) has discussed the work of the International Navigation Association's (PIANC) Working Group 41 to develop guidelines for managing wake wash and notes that wash is highly dependent on channel conditions and their interaction with vessel characteristics and speed. Slower vessels can also produce large wakes depending on the channel depth. Effective management of wash requires an understanding of how wash creates risk in a specific site for property damage, to persons on the shoreline, and to the environment. The working group therefore is developing guidelines for a careful, site specific, risk based evaluation process for wash effects rather than generic standards.

A properly planned ferry system can be an ecologically effective, and may give important opportunities for environmental improvements beyond just ferries.

Induced Demand

It is worth discussing "induced demand" here, as it is an important concept for evaluating the beneficial effect of any type of transit. This concept suggests that building transit corridors (freeways, bridges, and ferry routes) is, in the long run, hopeless. The existence of a convenient corridor will induce decisions to use it as opposed to not traveling at all, until the new corridor is as choked as the old ones. Therefore any and all improvements in transit should be opposed. In the case of ferries, this suggests that instead of reducing traffic congestion, ferries will just induce more people to drive who would not have traveled at all. Therefore, a ferry system cannot reduce congestion or any of its effects in the long run. However the validity of induced demand, and its magnitude, has been questioned recently (Cervero, 2003). A substantial part of induced demand is presumed due to construction along a new corridor, and concepts such as ferries that do not provide such opportunities may not be subject to this effect. However, the most important issue is that new corridor construction and increased demand may not be cause and effect, but rather joint effects of a third cause, essentially general trends to growth in an area. (In other words, what is perceived as induced demand is actually good planning.) Clearly, the opposite is not true; providing good transportation in economically disadvantaged areas does not always make them grow. Travel is strongly linked to employment and transit expenditures, and is probably most strongly linked to employment growth, increased household incomes, and the growth of two-worker families (Crane and Chapman, 2003).

Safety

Small passenger ferries have a very enviable safety record, especially in the United States. This is a social benefit of a ferry system; riders of ferries are less likely to be hurt or killed in automobile accidents. Despite this, ferry opponents have raised safety issues, concerned that dozens of fast ferries shooting around a busy harbor at high speeds will change this paradigm. As a result, there have been calls to go to the International High Speed Craft code (HSC) from current Coast Guard regulations. The wisdom of this is somewhat questionable. The HSC envisions vessels on international voyages, and envisions a "total system" type of approach to safety, including looking at the availability of local rescue resources, and the type of institutional systems the owner has in place to minimize accidents, which is a reasonable idea. The traditional Coast Guard regulations appear to look at each individual aspect of a ship separately, concentrating on detailed prescriptions for design, construction and equipment. However, this is not really the case. First, the Coast Guard is willing to accept innovative solutions that offer "equivalent safety" in most cases, so there is actually much more flexibility in practice than a simple reading of the regulations would suggest. In fact, it is this doctrine that would allow Coast Guard to accept the HSC as an alternative.

The HSC also envisions a very different regulatory environment than would be the case for a publicly owned ferry. It envisions privately owned vessels, traveling between nations on fairly long runs, at least several hours, often flying “flags of convenience”. It therefore becomes difficult for maritime safety agencies to build the kind of cooperative structures that the Coast Guard has with operators who do not cross international boundaries, especially public agencies subject to other types of oversight as well. The Coast Guard has built up numerous flexible regulatory structures of this type. As regards fast ferries, the Coast Guard has developed Navigation and Vessel Inspection Circular (NVIC) 5-01, working with the Passenger Vessel Association, which has a much more flexible, and proactive process that allows case-by-case cooperative development of optimized procedures that are closely tuned to a given service, route and type of vessel. The Coast Guard is also currently developing a new NVIC to extend the efforts of NVIC 5-01.

Use of a new “International” rule might seem to be better, but, especially for publicly owned ferry systems, the existing regulatory structure, combining the traditional rules with a cooperative development of appropriate additional safety processes, is probably more cost effective, and safer.

Equity

Another issue is equity – ferries have come to be seen to be elitist, though largely for irrational reasons. This is especially important for modern urban ferries, as ferry (or other mass transit) systems are frequently publicly subsidized so non-riders subsidize riders through bridge tolls or taxes. One reason that modern ferries may seem to be elitist is that they resemble yachts, and the image of commuters working on their laptops in a shiny white yacht may rub some people the wrong way. It may be worth reducing the elegance of the ferries somewhat, especially where the changes also reduce costs. The most obvious change would be careful selection of color – note that the Staten Island ferries are International Orange, and Washington State ferries are largely green. Both of these colors avoid the impression of “yacht” or “luxury cruise ship”, and both colors that also reduce maintenance, since though they fade, do so less obviously than most whites, which yellow. If the vessels are aluminum, they can be left unpainted. As to the interior, the most durable interior treatments (generally seen on military vessels) have an acceptable appearance, but are distinctly functional rather than luxurious. High ticket prices also increase the appearance of elitism; an expensive fare will be seen to be favoring the wealthy, but so will large subsidies, so minimizing the absolute cost of a system is important.

Looking at it rationally, whether a ferry service is equitable is simple: Those who benefit from a public work should pay for it; and those who pay for it should benefit. Automobile drivers who “pay” the subsidies in the form of gas taxes and bridge tolls can be particularly aggrieved, but they should realize that there is a structure of subsidies on automobile travel so pervasive as to be invisible (Litman 1999). In the Bay Area, transit subsidies also come from sales taxes, which are regressive in their effect, so the claim that the poor are bearing an unfair load has some credence. A ferry system must therefore have, and be shown to have; benefits that flow to non-riders, including those who don’t use transit or even commute long distances at all. It is relatively easy to perform this type of analysis for automobile traffic. The current ferry system operating between Marin County and San Francisco is the equivalent of one bridge lane, and is certainly less expensive. Studies by Shrank and Lomax (2001) place the annualized cost of traffic congestion at $2,805,000,000 in the Bay Area in 1998 for 58,855,000 daily vehicle miles traveled and $3,055,000,000 in 1999 for 59,750,000 daily vehicle miles traveled, with a negligible change in available lane miles. The difference in cost divided by the difference in daily vehicle miles suggests that the incremental value of taking a vehicle off the road each day for a mile is $294 per year. If every 1.5 ferry riders takes a car off the road every day, for the round trip from Berkeley to San Francisco ferry transport is worth about $1.78 per mile of the sea distance between terminals to drivers. Essentially, by subsidizing a ferry system from bridge tolls (as in San Francisco), that part of the subsidy is quite “clean”; bridge users are paying other people not to get in their way as they cross, by providing them an alternative. In fact, a simple analysis of a Berkley-San Francisco ferry suggests that riders could (theoretically) be paid five dollars per trip instead of being charged at all and drivers would still net a benefit. However, people who don’t cross bridges often also pay. Even if sales taxes and other general revenues don’t go to ferry subsidies, they “pay” by loss of waterfront and other effects, so there need to be demonstrable benefits to them as well.

It is worth noting that as a form of public transportation, a ferry can be legitimately argued as being more equitable than the automobile, provided there is reasonably effective public transport access to the ferry terminal, due to the large number of people who can’t drive or own a car. For example, one aspect of growing importance in the US is the fact that eventually, if each of us lives long enough, we eventually will be unable to legally drive. This loss of mobility has a disastrous effect on the quality of life for elderly people. Another group that will see the benefits of increased mobility is visitors, especially visitors to the central city. Increased mobility means that

Figure 1

car rentals are less needful, or that visitors without cars can do more. A ferry system is a very substantial benefit to these visitors as many of those not renting a car will be in central city hotels near a central ferry terminal (and they will therefore tend to be “backhaul” cargo).

Parking

Parking is often the single most important issue in a ferry system, much more important than any marine issues. Ferry advocates often hope that riders will travel to the terminals by public transit, rather than by automobile. Unfortunately, the same problems that limit using public transit for the whole trip limit it for part of the trip. In fact, it is possible that ferries will actually increase the number of riders who use their cars, though not the mileage of travel, since they will not be going into the central business district and will not be discouraged by congestion on bridges and tunnels and the high price of downtown parking. Environmentalists often seize on this to suggest that a ferry system results in net harm, but this is probably not completely accurate. Car riders, in avoiding the worst choke points by taking the ferry, idle less and cause less congestion, which is why they are taking the ferry, anyway. However, a ferry needs to optimize the use of parking resources, especially because vast parking lots occupying scenic shores are a visible and excessively adverse impact. This is a very serious issue – the inability to get adequate terminal parking, or local community opposition to potential parking impact, has sunk more than one ferry project.

Opportunities and Technologies

Show that the Route is Viable

A ferry system must offer a higher level of service, as considered by enough riders to make the system viable, than other modes. Level of service is the overall measure of all service factors that affect users and includes speed, price, amenities, convenience and comfort, both on the vehicle itself and in the terminals. The perceived level of service and what factors make it up also varies strongly from rider to rider according to both practical and emotional needs. Hockberger (2003) notes that the best ferry route is one to an island without any bridges, but the idea is that the competing land routes should be very much longer than the sea alternative. This means, in an urban setting with bridges and tunnels, the best ferry routes are most often the shortest sea runs. It would also be nice to have good existing infrastructure and reasonable separation from existing chokepoints.

One good example is the Berkeley/Albany to San Francisco route, which was selected as one of the first tier new routes by both the Bay Area Council and WTA. There is historical validation as well, considering that there was regular commercial ferry service from the Berkeley Pier to San Francisco from the late 19th Century right up until 1956, a full two decades after the Bay Bridge was opened. The Berkeley waterfront has the advantages of relatively short distance to San Francisco, but also a reasonable separation from the approaches to the Bay Bridge, and the BART tunnel. Separation, especially where it does not increase route distance or move terminals away from population or destination centers, improves the ferry's ability to compete against wheeled alternatives. In many urban areas existing recreational marinas offer opportunities as well, especially since marinas are less used during the peak commute periods. The Berkeley Marina, either at the original ferry pier (which is now used for fishing), or in the marina at the hotels along the inner shore, offers extensive existing infrastructure:

Deep water, requiring minimal dredging
Existing bus service
Existing parking (within certain limits)
Existing four-lane road access
Existing compatible land uses in the form of commercial, recreational and maritime facilities already in place.

Select the Right Speed

Transit authorities have put a great deal of resources into new technologies to reduce engine emissions, increase efficiency and suppress wake, and especially to increase boat speed. But for reasonably short routes, which are the most competitive candidates for urban ferry routes, the first thing to do is slow down. Passengers do not care about fast boats. They might want fast trips, and their trip begins at home and ends at work, so a fast boat is not the only, or often even the most important issue. There is also some question about how much they want fast trips, and that varies from service to service. Figure 1 shows a dramatic effect of speed. Passengers did not care enough for fast trips to keep the Seattle area fast passenger ferry running. This ferry carried passengers only, at higher speed, but at a cost premium compared to the larger, slower car and passenger ferries. On the other hand, the

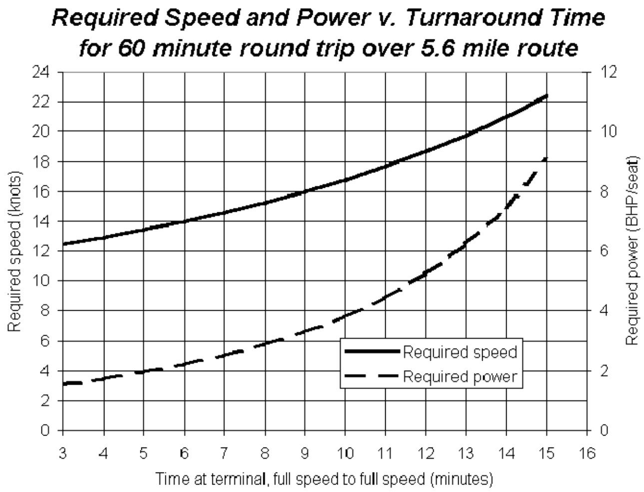


Figure 2

additional speed of some of the New York City services seems to be well enough valued that they are run at a profit.

The important concept for the non-naval architect transportation planner to grasp is that propulsion power is roughly proportional to speed cubed, and most costs are therefore also proportionate to speed cubed or at least squared. That is, if speed doubles, required power multiplies by a factor of eight. This is a direct consequence of the nature of frictional resistance, which is roughly proportional to speed squared. Power equals resistance times speed, so when speed doubles, resistance increases by a factor of four and power by four times two, hence a factor of eight, or possibly much more for higher speeds.

All costs associated with engines - first cost, maintenance and operation - scale roughly with power. (Although fuel consumption and emissions, on a per mile basis, scale more closely to speed squared, not cubed, because per-mile effects are all divided by speed.) Therefore the "right" speed is generally the minimum speed that offers acceptable service. For the relatively short 5.6 mile route from Berkeley to San Francisco, there is little incentive to reduce transit time to much less than 20 minutes. ("They need at least twenty minutes to buy a latté and open up their laptops.")

A 20 minute transit facilitates single-vessel operation on a simple-to-remember hourly schedule, or two vessels on 30-minute headway. Figure 2 shows the relationship between turn-around time at each end of the route (defined here as full speed approach to full speed after departure) and required service speed to meet the 60-minute schedule. Assuming ten-minute turn-around, a service speed of only 17 knots is required.

A commute ferry has another issue affecting optimum speed; vessel productivity. Though all ship designs have to trade cost of speed versus rate of goods moved, there is

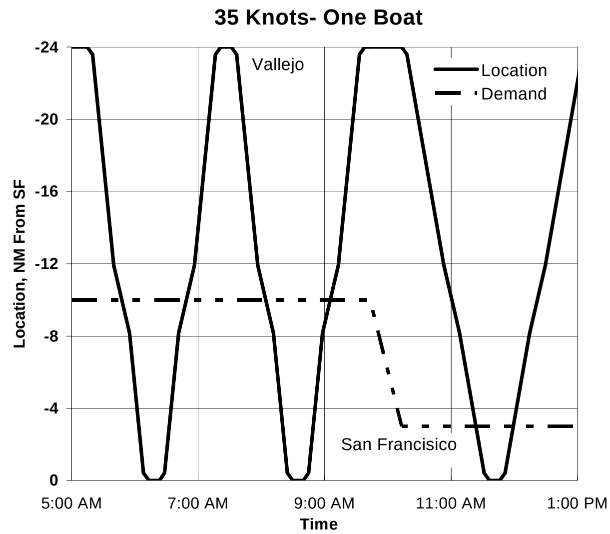


Figure 3

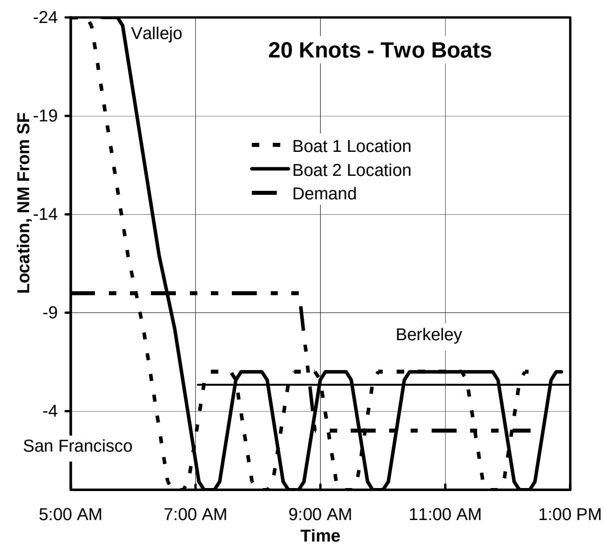


Figure 4

about a two hour or so band of time each day, each way, during which there is substantial passenger demand. The ferry has to be fast enough to make as many trips as possible during the rush. If a run is fairly long, this requires substantial speed. Figure 3 shows the location of a ferry running between Vallejo, California and San Francisco as a function of time of day, over a passenger arrival time demand curve. Note that in order to make two trips in the rush hour, a fairly high speed is required. Later in the day, the boat can "slow steam" to save fuel when the demand for fast trips is reduced (a simple strategy which might substantially affect the results of the environmental studies). Figure 4 shows an alternative strategy: two slower, smaller boats leave at different times, thereby supporting the travel demand, but in each case, after a single trip to San Francisco, they go onto a short run. This kind of strategy might reduce the demand for speed in an integrated system such as San Francisco. Note also that the Potomac River Jet was intended to spend mid day on short runs in the immediate Washington DC area.

Provide Appropriate Amenities

Ferries also can offer amenities unfeasible on other modes, (including, of course, a pleasant boat ride) again because of space, and because of open deck areas. Even if food service is not provided aboard, most ferries can allow people to bring food, can enable snack service at or near the terminal, and can provide space and quiet to consume food. Restrooms are required on ferries, and on the Seattle ferries are very important for riders preparing for work. It is said that the hair dryer outlets consume more power than main propulsion in the morning. Spacious interiors are beneficial for some persons with disabilities, and open deck space (and benign weather) can allow riders to bring bicycles or companion animals, which are important issues for some riders. (Disabled persons, cyclists and even dog owners can be substantial advocacy groups in some areas.) Amenities also extend to terminal design and features including security and comfort features as well as the opportunity to buy a latte.

The key problem is to determine those features that contribute to a high enough level of service to attract sufficient patrons, which may produce surprises. For example, some ferry riders prefer a slower ride as it allows enough time to read the paper or finish a snack. (There is a legend that the lengths of *New Yorker* articles are optimized for the Long Island Railroad commute into Manhattan.) One way that this can be determined *a priori* is to conduct extensive surveys, and the WTA is engaged in this now. However, in addition to the cautions normal for surveys, Hockberger (2001) offers some cautions specifically to ferry planners, most notably that responses to polls aren't commitments and aren't based on real world experience by those polled. The authors would like to offer an additional amplification on one of Hockberger's comments: Ferry travel is perceived as fun and pleasant, especially by its enthusiasts and those not using it every day, but for most travelers, transport of any kind is a means to an end, a "pain in the rear" to quote exactly, in the long run. Travelers eventually decide on modes based more on disutility, negative factors, than positive ones. Ferries have some probable disutilities, including cost, the inconvenience of connections and probably time. Planners need to work on minimizing negatives and to account for this sort of "honeymoon effect" in their polls.

Configure for Economical Operation

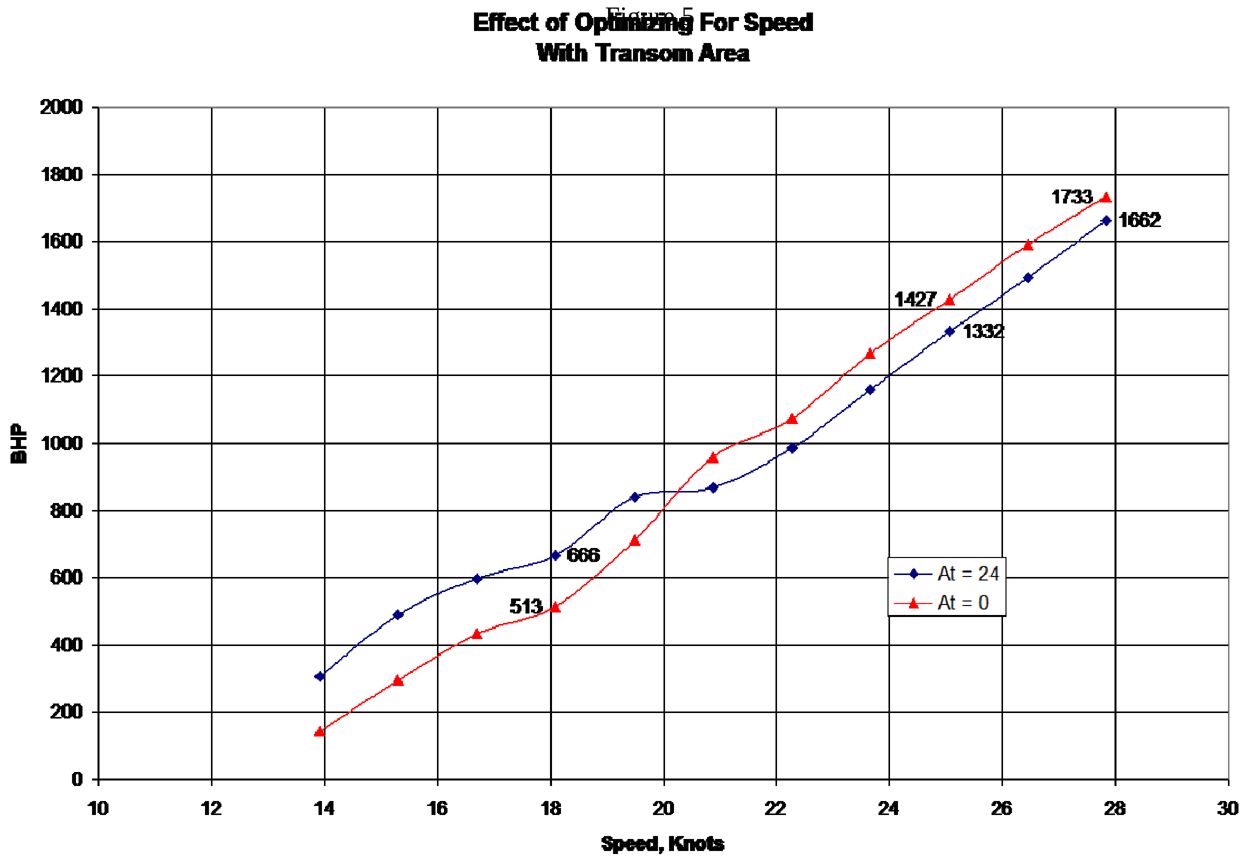
One major choice is the fundamental hull form. Although catamarans have become fashionable for ferries, there may still be conditions in which other solutions are superior. The idea of a catamaran is that the wave making drag of a boat is roughly related to beam squared, so slender hulls are much better. However, the minimum beam of a monohull is limited by stability concerns. The cat solves this problem with the two widely separated hulls providing the beam needed for stability. However, there is also frictional drag, due simply to the amount of wetted area, and here two slender hulls generally have more wetted area for the same weight than one broader one. As a result, catamarans are not necessarily better than monohulls with regard to resistance, especially a slender monohull. A cat is better than the "equivalent" monohull assuming the two hulls are "squished" into one sideways, but quite inferior if they are squished into one lengthwise. Cats have an advantage of greater deck area per weight, but have more structural weight per payload weight, and tend to cost more per unit structural weight. They can have reduced roll amplitudes, but can also develop severe snapping motions (high accelerations) in adverse sea states.

It is worth pointing out that if you had said "fast commuter" at the turn of the 20th century, you would have been referring to a class of quite fast (20 knots or more) yachts used by wealthy individuals, not the public, for commuting to work. These yachts were characterized by very slender hulls by current standards (ten beams or more long). Since these vessels were generally steam-powered, they were also relatively low powered by current standards. This concept in vessel design might still be applicable to some routes today.

The authors did a quick design analysis that suggests that a 149-passenger ferry might be feasible with seating equivalent to interstate bus or first class airline spacing, in a 120 foot by 15-foot craft. The beam could actually be reduced further, but the hull was chosen as the narrowest from the NPL High Speed Round Bilge Series (Bailey, 1976). This vessel would have acceptable intact and damage stability characteristics and requires power on the order of 1300 BHP to make about 25 knots. Such a vessel would probably require some type of roll stabilization, but active fins are well proven for such craft, and considering the relatively high speeds, passive fins with stall resistant sections might be sufficient. Rudder roll stabilization, anti-roll tanks or even recent concepts using high-speed gyros might also be feasible. Such a vessel would not have enough deck area for moving around and for the extra amenities common on many new catamaran ferries, but this space might not be a significant factor for short runs. It is also worth noting that such relatively narrow vessels with bus-like seating are common in ferry service on rivers and in inland waters in Southeast Asia.

Slender monohulls don't tend to be treated kindly by the current U.S. tonnage regulations, though. In the case of a short run ferry where there is little need for passengers to wander about during the short duration passage, a slender monohull with "bus style" seating and roll stabilizing fins or tanks might be a very effective design, with lower first cost and lower fuel costs than a cat. (There are also a

Figure 5



number of new roll stabilizing systems coming on line that use large gyros to actually produce roll resisting forces. Though gyros were occasionally used for roll control in the 30’s, advanced materials and low friction bearings have made very high rotational speeds feasible and thus reduced the required rotating mass substantially.) This is an example of the type of study that is important to optimization of the whole system – would such a vessel, with much less space and fewer amenities have a perceived reduced level of service and be uncompetitive, or do passenger really want a lot of space on a short route? Would the reduced level of service be compensated for by reduced costs? Would a lower cost vessel allow more boats on a given run and thereby increase convenience enough to account for the reduced amenities?

It also is worth remarking that many recent catamaran ferry designs are too narrow from a hydrodynamic point of view, i.e. their hulls are too close together. The hydrodynamic optimum is to separate the hulls such that a line nineteen degrees off the centerline of one hull does not touch the other hull. This is the angle a wave front propagates at, so this separations means that the two hulls will not hydrodynamically “see” each other and will not produce interference effects that might increase resistance. This requires a total beam of almost half the length, which is very wide.

Other options for multihull configuration are trimarans and proas. A trimaran has three hulls, (the outer hulls are called “amas”) and can range from a very slender monohull with small hulls as sort of “training wheels”, to vessels with three largely identical hulls. A number of advanced large high speed military craft are configured as “small ama” trimarans, notably the Royal Navy’s *HMS Triton* one of the two prototypes for the US Navy Littoral Combat Ship. Proas have a main hull and a single ama, and are thus asymmetric. In general the single ama is nearly the same length as the main hull, but generally much narrower.

Trimarans and proas both have the considerable advantage of potentially reducing total wetted surface while increasing hull length. This reduces both viscous and wave-making drag over the catamaran. Trimarans and proas also have the potential advantage of using only one engine and drive system instead of two, for a potential economy of scale. However, real-world examples have tended to negate this advantage due to drag on the amas (outriggers). Traditional human-powered outrigger vessel types have dealt with this shortcoming by minimizing the displacement of the ama, and relying on human factors to avoid capsize. It is interesting to note that as vessels become larger, the relative negative effects of the stabilizing ama become smaller. This is because heeling forces are generally a function of wind area times height, and scale up by size cubed. Righting moment, on the other hand, scales by displacement times beam, or size to the fourth power. So as a trimaran or proa configuration scales up, the relative size of the amas can be reduced and the resistance penalty becomes a less significant negative factor.

Good design is also important. This includes selecting the appropriate requirements for the hull and selecting a good hull. Figure 5, based on the NPL high speed displacement monohull model series, shows the importance of design for the appropriate speed. In this case only one geometric parameter, transom area ratio, is varied, and is optimized for either 18 knots (transom area, A_t, of zero) or 25 knots (transom area, A_t, of 24 square feet) in an 80 ton, 100 foot vessel with the same beam, and draft. (Varying transom area requires changes in LCG, aft prismatic and wetted surface.) The performance loss at the non-optimum speed in each case is substantial – you can't assume the best fast boat is the best slower boat. This is especially important for high speed craft, which can be very uneconomical at low speeds – not only are the hull forms wrong, and have tremendous wavemaking at low speeds, but the propulsion systems are usually off optimum as well. Low speed propulsion usually is optimized by large diameter, fully submerged propellers; whereas high speed craft often have water jets (the change of propulsion method also requires changes in hull design). As a result, the differences in optimum power at each speed are usually much more dramatic than shown here.

Tonnage

Another important issue for ferries is tonnage regulations. The size of a ship, for taxation and regulatory purposes, is generally determined by its internal volume – its "admeasured tonnage". The US currently uses two tonnage systems; the International system, which harmonized the many different rules of the maritime nations, and is a formula based on essentially all the ship's internal volume, and the traditional "regulatory tonnage", which is the internal volume in tons of 100 cubic feet, but includes numerous curious exemptions dating back to 1865. The importance of an extensive network of wide navigable rivers in the U.S. during its period of rapid industrialization produced a type of fairly large river boat with nearly all usable space above the main deck. Successful lobbying by steamboat operators resulted in tonnage exemptions for nearly all the volume above the main deck. It worked fine for steamboats on the Mississippi and Missouri rivers, but after 140 years of evolving loopholes and regulations, it is assumed that any vessel exceeding 100 gross tons is quite large, so the breakpoint between large and small passenger vessels was set at this point. Thus current U.S. tonnage regulations are extremely type-forming, encouraging designs that are short and high. Because they are high, they also tend to be wide for stability. Because framing depth can be deducted from measured volume, large modern ferries often carry extra structure in deep frames for no purpose other than keeping the tonnage number low. Vessels built to optimize U.S. tonnage rules are inefficient and uncomfortable. Long slender hulls measure poorly, so U.S. ferries tend to be short and fat, with extra framing and other unnecessary features. Unfortunately the International rules, though more rational result in much larger numbers. Under the International system, vessels pass the 100 ton mark at about 80 feet long – large yachts are generally built to a 500 gross ton International limit, and are generally about 150 feet long. The 730-passenger Golden Gate Ferry "Spaulding" monohulls are less than 100 tons under the U.S. system but would probably be 400 ton vessels under the International system and there are numerous 99.9 gross ton casino boats now in service that measure over 1600 International Gross Tons.

The Coast Guard is in the process of setting new regulatory break points that are consistent with international practice, but this is a very complex project, since tonnage numbers are involved in a wide range of regulations, so achieving stability, consistency and fairness including a transition from the existing situation is not a trivial problem. Though no-one wants to be the last agency to build, buy or operate ferries under the old rules, there is another alternative: A surprising number of vessels, mainly historic craft, but at least one ferry, have been granted various forms of relief, often through special acts of Congress. It may be worth pursuing this in that such relief would not give an unfair competitive advantage for new operators, since they are new public agencies anyway and would ultimately result in a savings to taxpayers.

Design for Very Fast Turn-Around

The dashed line in figure 2 shows the substantial reduction in required power for every minute saved at the terminal, assuming the 60-minute schedule is a constant. This is reflected in reduced first cost, increased fuel economy and reduced emissions. In order to interface with a terminal designed for very fast boarding, the design should feature very wide side decks to allow easy alternative access to multiple gangways, not only to allow large crowds of people moving at different speeds, but so that passengers moving in opposite directions won't interfere with each other. Loading and unloading of bicycles, wheelchairs and pets should not slow down the embarkation/disembarkation process at all. Historically, the method of ticketing and payment control has been a dilemma: Should passengers pass through a control point before boarding and then wait in a confined area for the boat to arrive? Or should the control point be at the gangway, allowing passengers more freedom while waiting but slowing down the boarding process? Or should tickets be checked while underway? All three methods are in use, and all have drawbacks, but it can be predicted with reasonable certainty that remotely-read electronic tickets will soon tip the balance in favor of the gangway as the control point.

Minimize Terminal Delays

Passengers generally don't care how fast the ferry travels. But they do care how long it takes to get from home to work. It has been shown that when travel times to the terminal are variable, commuters will generally try to arrive two standard deviations ahead of the mean departure time. This variability in travel time, however, has to include all variables that affect the trip from front door to ferry gangway. For most passengers, this includes the variability in the length of time required to find a parking spot and to walk back to the terminal from this spot. This variability has just as great an impact on trip time as variable arrival and departure times of the ferry itself. Running the ferry exactly on schedule is therefore only part of the operational goal. In order to provide fast door-to-destination service, it is important to eliminate as many variables as possible from both the shore side delays and the ferry departure time.

This implies more than "just adequate" parking. There needs to be enough parking so that the variability in finding a parking spot is minimized - meaning very little chance of encountering a problem finding a space right away. If parking scarcity is used as a method of discouraging cars in favor of other modes, then variability is very high, trip time increases dramatically, and the viability of the entire service is seriously diminished. This also suggests that parking should be made as efficient as possible. One possibility is a system taken from the Toyota Production System: An *andon* is a signal light that shows the status of a work station in an assembly line. Current technology easily allows devices that detect an auto in a space, and display appropriate messages to guide drivers to empty spaces rapidly. This could be as simple as a light tower on the end of each aisle, with a colored light at the top of a column of white lights. The white lights would roughly indicate where an empty space would be in the row, and the colored light would go from green for many spaces, to yellow for few and red for none.

Include Everyone

Public hearings are not accurate surveys of public opinion, nor are they objective expressions of the democratic process. But in the absence of a scientific survey or a fair election, the self-selected voices at public hearings are often taken as the best available substitutes for both. Planners know this, and usually do their best to compensate. Ideally, public officials should try to restrict their use of pubic hearings to flagging unanticipated problems and generating new ideas. But the squeaky wheels still get more grease, and most public undertakings rely on a preponderance of favorable public comment, biased heavily in favor of those who have their weekday evenings free. Ferry service can motivate some powerful interest groups, and their participation in the public discourse can easily shift this perceived balance of public opinion in favor of a project that includes them.

Aside from political expedience, inclusion of user groups not served well by other transit modes is one of the things that ferries can do best, and is perhaps one of the more valid arguments in their favor. Bicycles are not allowed on BART during commute hours. A ferry with large outside deck areas and multiple gangways can accommodate bicycles with almost no annoyance or inconvenience to other passengers. Bicycles are also a useful strategy to defuse the charge that ferries are elitist, provided their riders enjoy a deep discount. Wheelchairs are now accommodated on all public transit, but a good case can be made that wheelchair access to ferries is - or at least can easily be - relatively seamless compared to bus or rail. Powered scooters present interesting possibilities. Like bicycles, they allow the ferry passenger to exploit the efficiencies of a "dual mode" transportation system, greatly extending range at the destination without the delays associated with a mode transfer. New configurations of electric scooters (e.g. the Segway, invented by the author's long-lost fifth cousin) offer particularly compact stowage possibilities.

Dogs and their owners are another example of “everyone”. Dogs can evoke the most controversial reaction, but their owners represent approximately one-quarter of the population, and dog owners are excluded from most transit opportunities. Though relatively few dogs commute to work, they do travel with their owners on off hours, so they improve off-peak use. A pro-dog policy can have a profound positive effect on any proposal - although care must be taken insure effective separation for the considerable segment of the population that does not want to share space with dogs in any way. Once again, multiple gangways and large deck areas make a dog-friendly policy feasible. But can dogs, bicycles and wheelchairs can mix it up on gangway number 3 while everyone else boards quickly through gangways 1 and 2? Temporal separation seems appropriate - i.e., they can take turns. Total numbers are likely to be a small fraction of the total passenger load, and with terminal and vessel design that anticipates these users they will not add anything to the turn-around time.

One of the few areas of small-craft recreation that is now experiencing a strong growth rate is hand-launched watercraft, e.g. kayaks, windsurfers and outriggers. They have one major obstacle to water access over most of San Francisco Bay: Lack of parking near the water. Ferry terminals, because they usually involve large parking areas with peak use periods that generally do not overlap with recreational use periods, have these recreational communities as a natural ally if minimal access facilities are provided. Ideally, the hand-launched watercraft dock and the ferry boarding area would be at opposite ends of the parking area, so that neither user group competes with the other for prime parking spaces.

The importance of these user groups at contentious public hearings cannot be overemphasized - they are generally articulate, credible with the environmental community, and often have a strong emotional attachment to water travel.

Local opposition from non-riders at one end or the other of the route has scuttled other system proposals. Some proposed New York area systems have met fierce opposition from residents near terminal locations. After having paid enormous prices for homes in quaint shore side villages, homeowners understandably took a dim view of thousands of cars passing in and out each day. The operators of competing modes may also oppose ferry systems because they see a ferry system as “cherry picking” their best potential patrons. Of course, the recent demise of a system to carry gamblers from New York City to casinos in Connecticut (because it was unable to get a suitable landing facility) was solely based on technical issues, not political ones. The point here is that an important early step in a ferry system is to carefully select and groom terminal locations, and to either make friends with enough stakeholders to ensure sufficient support, or to give up quickly, before substantial money is spent on studies.

Respect the parking resource

Many ferry systems propose charges for parking. This is likely to meet strong opposition in any location adjacent to businesses and organizations that currently rely on ample free parking. One of the advantages of a terminal location in or adjacent to a yacht harbor is that it is already a commercial and recreational center. The Berkeley Marina is host to a number of restaurants, a hotel, several non-profit and commercial organizations and about a thousand private boat berths. They all depend on free and ample parking, made possible by reasonably good planning and the low-density nature of the existing waterfront. Turn a parking area into a fee lot in close proximity to any of these services, and it is not necessary to run simulation software to predict what would happen. Fortunately there are fairly obvious solutions: leave the parking free and raise the ferry ticket price instead. Offer deep discounts to people coming by bus and bike. The bus discount is easy to implement via transfers. The bike discount requires bringing the bike on board, and is subject to some level of abuse, but there are equally obvious countermeasures.

These discounts can result in exactly the same economic incentive as a parking fee to leave the car home, without destroying the neighboring parking resources. By this logic, pedestrian access should also be rewarded by a deep discount. But there is no clear way to accomplish this. Fortunately, one feature of marina locations is that there usually are very few residents within walking distance, so non-transit non-bike pedestrian access is not likely to be a significant factor. The ferry service could easily make some other contribution to the small (but vocal) Marina live-aboard community to retain their allegiance. This means that optimizing the parking resource is critical, and not only in large ways but in small ones too. If a lot has automatic empty space guidance, then people don’t cruise around the lot, have a quicker walk to the boat, and are off the neighborhood streets faster. Local business should also have validation privileges - since this would encourage ferry riders to patronize the business, it would change local business owners from enemies to allies.

Set the Price to Minimize Subsidy and Maximize Revenue

Higher ticket prices will affect the ridership levels, but the degree of elasticity for any given market is not really known.

In the case of San Francisco-Berkeley, considering the value of time lost during a Bay Bridge commute, and the possible productive value of time on the ferry v. time driving in traffic, it is likely that a significant market segment will happily pay the actual cost of the service - approximately $7.50 per one-way trip. Current WTA proposals suggest a $3.50 ticket price and a per-one-way-trip subsidy of about $4.00, but opponents could not support a subsidized service of any kind. This may have to do with the elitism issue or may be the fear that every dollar spent on ferries means one less dollar spent on busses and rail despite the fact that the WTA enabling legislation calls for all subsidy to come from new funding sources. For this reason it is critical to keep fares relatively high and subsidy levels low. BART subsidizes every trip to the tune of about $3.23 (1999 data - and it's about double that if we include capitalization of the ongoing route expansions, and there's no good reason not to.). Golden Gate Transit subsidizes each bus trip at the $1.93 level. AC Transit Transbay service is not easily separated from local revenue and costs, but it is probably somewhat less than the Golden Gate Transit figure. All this suggests a maximum defensible subsidy of about $2.00 per trip. Otherwise, the "concerned public" (or perception thereof) will conclude that the money should be spent on more busses instead.

The more sophisticated argument is that the subsidy to compare is the marginal rate, not the average. The question to ask is "How much more public money do we have to spend to get one more commuter out of their car and on public transit?" With an extensive bus and rail system already in place, the number is considerably higher than the system-wide average per-passenger subsidy. New bus routes and schedules serve the less popular areas and times, and load factors are unfavorable.

New rail service can only be provided at astronomical infrastructure costs. Here is where ferry economics look great: Hardly any new infrastructure is required (except relatively cheap, by rail transit standards, terminal development). And, with some high-demand routes now going totally unserved, a well targeted service with a high ticket price and low subsidy is likely to work. In other words, busses and trains have to attract that last passenger, who comes at a high price. But ferries on new routes can go after their first customers, and they come relatively cheap.

The Diamond Lane Strategy

The political downside of ticket pricing set at or near market rate is that the service proposal will be wide open to charges of blatant elitism. "Ferries are only for rich people" is the call to action against new urban routes. Actually, this charge has little merit as long as the cost of a round trip ferry ride is less than the cost of a daytime parking space in the financial district, but the charge will be made nonetheless, and a successful plan needs to defuse these criticisms. The diamond lane strategy takes the same approach as the free HOV lanes found on many urban bridges: If you are treading lightly on the infrastructure and the environment by driving a carpool across the bridge, then you get a free pass around the traffic and don't have to pay the toll. There is equal justification for doing the same thing for ferry passengers who arrive by bus or bike: A free ride, or at least a very deep discount.

This policy has two desirable effects: It essentially charges for parking without the negative impacts that fee parking would have on adjacent uses that depend on free and ample parking; and it also makes the ferry a very accessible option to people who would otherwise be priced out of the ferry market.

Other alternatives might include changes in parking fees based on time of day, so that afternoon, evening and weekend parking is free. Remote park and ride lots have also been proposed for some ferry systems. Litman [2006] covers various strategies for parking regulation to optimize use of the resource.

Improve Utilization

Another important part of this strategy is to maximize “back haul”. An empty seat costs the same to move as a full one, so selling it at a discount is free money – “nothing thrown away is ever sold at a loss”. This is the same sort of problem that results in the whimsical world of air fares, but in this case, we know when and where the low occupancy runs are, and we can develop strategies to maximize occupancy on them. We could, for example, have a deep discount for the counter-commute direction. Since counter-commuters generally drive alone, this is could have a better impact on reducing emissions and even congestion – the counter commuter is on downtown San Francisco city streets getting on the bridge at the same time everyone else is on the street getting off. In the specific case of Berkeley, students from San Francisco would be counter commuters. Even if a boat slow steams during the day, it is still spending crewing pay, and off hours discounts could help fill the boat.

This strategy might not, strictly speaking, reduce congestion much, because the users would probably be many people who wouldn’t travel at all otherwise, but it would improve mobility and transit opportunity equity and provide some farebox revenue, all legitimate goals. This could be further “sweetened” by targeted discounts, such as student and senior reduced fares for these periods, which would increase special interest group support. One of the authors has some experience with some of these lobbies, and though our references to the dog lobby may seem whimsical, this one of many special interest groups that have substantial “bite” and well as “bark”.

Use Proven Technology for Emissions Reduction and Energy Efficiency

WTA and other agencies have directed considerable resources at new technologies to reduce emissions from ferry propulsion. Compared to the existing base of commercial and recreational marine diesels in daily service without any emission controls, this may be seen as a kind of drop-in-the-bucket environmental tokenism.

Nonetheless, tokens can be important, and can stimulate cultural changes that are far more important than the tokens themselves. And of course the political reality is that ferries will have to leave a spotlessly clean wake in the air, water and land in order to avoid continuing and damaging attacks from environmental organizations.

But accepting the need to dramatically reduce emissions does not mean that operators need to engage in original research. Spark-ignited compressed natural gas (CNG) engines are already in widespread use for applications that require extremely clean exhaust. The mandated 80% reduction in emissions has already been achieved on a commercial scale for applications very similar to the ferries proposed for the new routes. Currently available marine Roll-Royce Bergen engines meeting WTA’s target emissions – without exhaust gas treatment - have been specified for a new “green” Norwegian ferry.

CNG may be much better suited to short-range ferry service than to many other applications, due to the bulk of the fuel containers and the limited range between refueling. CNG also slightly reduces carbon dioxide emissions – methane ($C H_4$, the principal component of natural gas) has 28,691 Btu per pound of carbon whereas as decane ($C_{10} H_{22}$, a typical component of diesel fuel) has 22,690 Btu per pound of carbon.

Where we go astray is confusing the more exotic, less reliable or more controversial technologies (fuel cells, wind assist, biofuel) with mature technologies offering proven solutions. The most egregious error remains the one that is the simplest to fix: speed. Most projects that purport to demonstrate the feasibility of sail assist, solar-electric or fuel cell propulsion appear to be extremely energy efficient because they go slow, and not because of their alternative energy source. WTA still proposes 25 knot ferries for a route that only requires 18 knots. Approximating by means of the V-cubed relationship between speed and power, this is the same as asking for an engine 2.7 times as powerful as needed. In other words, the continued "fast ferry" mentality, misapplied to a short route, results in almost triple the propulsion system cost for acquisition and maintenance. The extra weight impacts the capacity and efficiency of the vessel at lower speeds. Per/mile fuel consumption varies by the square of speed, so the 25-knot boat will burn about 93% more fuel per mile than its 18-knot counterpart (neglecting the increased weight of the larger engines) over the same route. This simple solution - slowing down the boat - allows low power engines that will tolerate emissions controls without as much added weight or cost. In a rational ferry service proposal, existing technology will solve the emissions problem. For better door-to-destination travel time, innovative design resources are better spent on efficient deck and terminal design for fast boarding and quick turn-around than on new ways to go fast.

Keep It Local

Local jobs have always been a powerful incentive for development, and a ferry system is no exception. One of the authors originally entered the marine industry (at least in part) because he grew up in Vallejo, and was unaware that there were any occupations other than ship building and design. New technologies and methods have made it possible to increase productivity enough to build ferries competitively at very high labor rates. US shipyard productivity varies by a factor of at least three to one from average to best, and those shipyards with the best productivity are in relatively high wage areas (the Pacific Northwest and the New York / Connecticut area) anyway. There is no reason that a Bay Area or at least California shipyard could not “leapfrog” to best practices and produce ferries and similar ships at reasonable prices. The National Shipbuilding Research Program has been advocating and enabling just such a strategy for US shipyards for over a decade.

A shipyard building ferries could also take advantage of another trend; the boom in superyacht construction, by using ferry building as an entry into this market. There has been a boom in the superyacht market for several years now with no sign of an end. The current production is limited by construction slots, not the market. The slide of the US dollar has also made US construction much more competitive, since most builders of superyachts are in the EU, with a few in Canada, New Zealand and Australia, all of which have seen their currency rise substantially against the dollar. At least one major US ferry builder also builds superyachts, and since superyachts are often aluminum and generally registered as small passenger vessels to allow chartering, there is substantial synergy between the two product lines. A shipyard building ferries could also build a few Maritime Coastguard Act limit (500 Int’l GRT – about 150’ long) yachts a year and employ two or three hundred people at competitive wages. Fortunately, superyacht construction can be massively profitable as well, especially if productivity improvements based on CAD/CAM/CIM, “Lean” and “Six Sigma” from commercial and military practice are adopted (Oetter, 2006). Though construction in the Bay Area specifically may be difficult due to limited facilities or labor shortages, it is worth noting that the Humboldt Bay area has substantial surplus waterfront capacity, a job shortage, and a substantial base of skilled trades that could be readily converted to small ship construction, and this would at least keep jobs in California. The authors are not familiar with capacity in other areas such as Stockton or Southern California, but there are probably opportunities in numerous California communities. It is also worth noting that Washington State legally requires ferries used in Washington be built there.

Design/Build

One of the first decisions is how to acquire the vessels, and it is the current fashion in many ship acquisitions to use a performance specification, and worse to require an off-the-shelf design. One term used in some circles – “out house design” - for such buys may convey some of the disdain for this approach held by some designers. The key problem is lack of optimization.

Optimization is figuring out what the right things to do are, and then doing them right. This doesn’t often work for an off-the-shelf “proven parent” design or. To offer a non-marine analogy, the various dog breeds, which are literally “proven parent”, are all highly optimized for their tasks and environment, but the lesson from dog breeds is that “off the shelf” designs are rarely optimum for a new task and environment, and selection of an “off the shelf” design has its costs. Taking two breeds the authors are familiar with, the Nova Scotia Duck Tolling Retriever has the mild temperament and intelligence of a Lab or a Golden, the tolling behavior which lures ducks gives it a playful spirit, but it is much smaller, and better suited for a small yard (Coldwell, 2000). However, the “Nova Scotia” part is not so well suited for the milder Maryland climate, resulting in lots of shedding. Likewise, the white coat of the popular West Highland White Terrier was designed for small animal hunting, (it reduces the chance of accidentally shooting the dog) but is also glamorous. However, in modern service, a white lap dog that is also bred to dig aggressively has limits in polite society. Custom designed dogs are not feasible in the short run, but custom designed boats are easy.

In fact, "off the shelf" is a significant source of risk, because it is more "often off the shelf" with just a "few minor changes", which usually increase weight, hazarding speed and stability.

There is no real advantage to off the shelf either. Custom design of boats is a well established process, and there are so few ferries in the world that there is no real mass production to provide substantial cost savings. In addition, especially with computer tools, design is fast and only a small fraction of the total cost.

The authors would therefore like to encourage system operators to take more responsibility for ship design. Developing at least a contract level design in-house would be optimum, but this probably requires more internal resources than are available. However, an operator can do a two step design process, selecting a design firm, developing a design cooperatively with the firm, and then sending that out for bid.

Performance specifications are supposed to work because all the responsibility for performance is transferred to the builder, but this rarely works. If the builder fails, he rarely has resources to make the operator entirely whole, especially considering delays in beginning service, and there are always excuses that result in claims both ways – operators will rarely leave a builder entirely alone, but instead insist on various approvals and so on. This gives the builder an out – just like in basketball, the last team that touched the ball gets the foul. Performance specifications also ask more of the shipyard at the bidding stage, so fewer yards will bid. This reduces competition. Finally there is the most obvious drawback. Assume we evaluate three complete design/build proposals on three factors, best design, best quality builder and lowest price. There is only one chance in 27 that we will get the best of all three factors.

That said, the authors realize they are blowing against the wind, so we would like to make one suggestion – at least develop a point or validation design, a straw man that proves the specification works – using the final specification, so that there are fewer surprises when construction begins. It would be even better for planners to do "ship synthesis studies" using automated systems such as that offered by Eisele and Gupta (2003) to optimize requirements, and to determine the cost and system effectiveness effects of speed, passenger capacity, required emissions equipment and so on well prior to announcing the speeds, ship types and so on.

Long Term Support: Structural and Product Models

"A boat is a hole in the water, into which you pour money"

Long term maintenance and related support costs should have a great influence during design because support probably costs several times acquisition through the life of the vessel. Two new technologies that apply to any sort of vessel are offered here:

Structural modeling – The Coast Guard, and Defense Research and Development Canada as well as numerous commercial shipowners are maintaining whole ship Finite Element Analysis models of their fleets as a means of monitoring structure and optimizing maintenance and emergency response. This process generally uses MAESTRO or related software (ABS SAFEHULL for example) that uses a super-element approach to economically model and load the whole ship. Multihulls are especially sensitive to cracking and it may be wise to either obtain a FEA model of the vessel from the builder (which would allow early optimization of structure) or to obtain one subsequently.

3D CAD Product models – The Coast Guard, the Navy and many commercial ship owners are getting the Product Model that was used to design and build the vessel in the first place and adding links to integrate all aspects of vessels management and training. This uses Internet and video gaming tools to produce essentially a virtual ship. A user can click on an item of equipment and bring up links to manuals, maintenance records or even supply information. This is a rapidly evolving area of technology in all industries, especially consumer product lifecycle management and facilities management and the future operators are urged to keep an eye on developments.

Future Opportunities

Configurations for Best Efficiency at High Speeds

Despite the inefficiency of high speed ferries compared to wheeled modes, there will be routes demanding high speed across water. Planing hulls, hydrofoils, air cushion vehicles and wing in ground effect are all candidates over various speed and size regimes. Nature, however, gives us clear instructions for best efficiency at high speed over water: wing in ground effect.

Despite the incredible diversity and variety among biologically evolved systems, observe that there isn't a single species of animal that propels itself over water by planing. We find abundant examples of waterfowl that travel in displacement mode as surface vessels, we have oceans full of fish moving fully submerged, and we even have examples of marine mammals that surf, although they do this from just below the wave surface. There are, however, a huge variety of bird species, and a few fish, that use wing in ground effect. (Figure 6) But aside from a waterfowl skiing to a stop from a water landing, there are no animals that plane. No biological analogs to hydrofoils or active air cushion support either, for that matter.

Why? Because when traveling fast at the interface between a dense medium (water) and a thin medium (air) it is far more efficient to get lift from the thin medium near the surface of the dense one, instead of the other way around. More specifically, hydrofoil efficiency degrades near the free surface, because downwash angles increase and induced drag increases along with it. A planing hull is subject to induced drag losses too, and is always bound by surface effect limitations. But to the wing in ground effect, the water surface is for all practical purposes a solid wall, and it enforces a plane of symmetry. This suppresses downwash and reduces induced drag.

A fast ferry candidate of the future for long runs requiring lots of speed could derive most of its lift from wing in ground effect, because when the technology matures this will prove to be the most energy efficient by a substantial margin. However, because the economics and operations of these vehicles will resemble those of airplanes, the obvious question is, "why not just use an airplane? Answer: The WIG ferry does not need to compete for airspace or runways, both of which are in very short supply (Ebb, 1990). Pure WIGs are probably not the best solution for shorter runs in crowded harbors, though, but the lesson of another of the author's dogs (the "Half-Tide Spaniel", an unplanned hybridization that nonetheless worked out well) may prove instructive here as well – some of the most interesting saltations in both dog and boat design are hybrids that combine the best features of two species, and in this case, there is a partly hydrofoil supported WIG being developed as a ferry in the Chesapeake.

Figure 6

Hybrid Hydrofoils

Another obvious hybrid is a combination of hydrofoils and planing lift, which solve a variety of problems from pure hydrofoils. Hoppe and Migeotte (2001), for example, have been developing a series of systems comprising catamarans with hydrofoils between the hulls with substantial success, and several fast craft in service. The authors have worked on another option, the stepped hybrid hydrofoil, patented in a basic form in the '50s in Sweden (Barry and Duffty, 1999). A hybrid hydrofoil is a vehicle combining the dynamic lift of hydrofoils with a significant amount of lift from some other source, generally planing lift. The attraction of hybrid hydrofoils is the desire to meld the advantages of two technologies in an attempt to gain a synthesis that is better than either one alone. Partially hydrofoil supported hulls mix hydrofoil support and planing lift. The most obvious version of this concept is a planing hull with a hydrofoil more or less under the center of gravity. Karafiath (1974) studied this concept with a conventional patrol boat model and a hydrofoil. His studies showed large reductions in drag but also revealed that many configurations were unstable in pitch. Pitch instability is the chief issue in any hybrid hydrofoil. Planing hybrid hydrofoils can exhibit dynamic pitch instabilities similar to porpoising. This phenomenon can be best understood for a nominal configuration with a single hydrofoil beneath the center of gravity of a planing hull. If such a configuration is slightly disturbed bow up from an equilibrium position, the lift on both the foil and the hull will increase. The hull accelerates upwards and the intersection of the water surface and the keel moves aft. This develops a bow down moment, but at a relatively slow rate. By the time the bow drops enough to reduce the excess lift, the vessel is well above the equilibrium position, and the keel/waterline intersection is well aft. It falls back down toward the equilibrium position bow down, as if it had tripped on its stern. Then, it carries through equilibrium, takes a deep dive and springs up again. This cycle repeats, each time growing more severe.

The stepped hull concept is obvious from this discussion. The foil is at the extreme stern of the vehicle and a step is provided forward of the CG. The step confines the planing lift to the forward part of the hull so that the relative position of the center of gravity, the step and the foil control the proportioning of lift between hull and foil. Bow up pitch of the vehicle produces a strong bow down moment from the aft foil, directly proportional to pitch, that reduces the pitch much more rapidly than the movement of the center of planing lift. The step also means that the running attitude of the planing hull can be set at a trim producing optimum lift.

When the bow of a stepped hybrid hull encounters a wave, it will initially rotate like a planing boat, but the rotation will increase the angle of attack of the aft foils, which lifts the vehicle bodily upwards from the rear and reduces pitch acceleration. The hull is therefore "anticipating" the oncoming wave and goes over it. This motion has to be carefully tuned to the anticipated wave environment for optimum performance, but it is clear that a properly designed stepped hybrid hydrofoil would have excellent motions. Unfortunately this doesn't address roll stability. The lightly loaded forward hull and fully submerged foils provide almost no roll restoring moment if the hull is optimized for low resistance. The answer to this is a catamaran forward hull. Another problem is foil design. A foil optimized for high speeds would stall without lifting at the relatively low takeoff speeds. “Barn roof” modern foil sections, which resist stall to very high lift coefficients address this issue.

Propulsion is an advantage for hybrids. Unlike a pure hydrofoil, a hybrid can be propelled by hull-mounted components. However, a hybrid also needs a propulsion system that will not overload the engine in the takeoff condition. This can be achieved by surface piercing drives forcibly ventilated by propulsion machinery exhaust or jet drives mounted in the forward planing hull and discharging at the step. A final problem is the practical issue of building the foils. Pure hydrofoils require exotic, expensive, stainless steel foils. A hybrid is slower and has larger foils at optimum. These foils can be made by casting high durometer polyurethane (roller blade wheel material) in a simple mold over a high strength low alloy steel welded core, so the foils themselves are affordable.

Propulsion Technology

A large fraction of current waterjet applications would be more efficient with surface-piercing propellers. Unlike fully submerged propellers, surface-piercing propellers can be of arbitrarily large diameter and have arbitrarily large hubs, without hitting the bottom of the boat, the bottom of the ocean, losing efficiency from angled shafts or incurring a significant parasitic drag penalty.

Although they are still considered best for high speed race boats, the possibility of large diameters and deep reduction ratios means that the potential efficiency increment of surface-piercing propellers over other systems is greatest at medium speeds (Kamen 1990).

Deep reduction ratios (slow shaft speeds) and the large propellers and high torque drivelines that go with them are expensive, and first cost issues have kept this solution away from most of the market to date. But higher fuel costs are likely to boost the popularity of optimized surface-piercing propellers over waterjets. (Disclaimer - both authors are former employees of Arneson Marine, manufacturer of a surface-piercing propeller drive system).

Figure 6 also shows an optimal biological solution using surface propulsion as well as WIG: The flying fish uses wing in ground effect for lift, and a reciprocating surface-piercing propulsor for thrust.

Prime movers are likely to be spark-ignited natural gas or steam-injected natural gas-fired gas turbines. Both are uniquely suited to short runs where relatively bulky fuel and frequent refueling is not a major problem.

Figure 7

In the case of steam-injected turbines, a shoreside supply of purified feed water is important. But this is nothing new - consider the woodcut of Jacob's wharf, on the Berkeley waterfront, c. 1880 (Frontispiece). Note the circular tank on the pier, presumably to supply feed water to the walking beam engine.

Dual Mode

Looking further into the future, our speculative crystal ball shows a return to the dual mode ferry. Bicycles are the immediate practical dual mode application, but electric scooters are not far behind if ferry operators decide to allow them.

Taking the paradigm to land transportation, many transportation academics are advocating "dual mode" vehicles as the most likely long-term reconciliation between the car culture and sustainability. Dual mode promises the best of both worlds, providing the convenience and privacy of the auto, but attaining efficiencies comparable to rail when they enter a guide way and hook up with each other to form automated trains. One such system, (Jensen, 2000) developed in Denmark, is described in detail at http://www.ruf.dk/. Figure 8 shows what these vehicles and their guide way might look like. Why is this important for ferries?

Dual mode vehicles are likely to be very compact, have uniform cross-sectional dimensions, nest very tightly front-to-back, and have the ability to be remotely and automatically driven with high precision, especially when on a guide way system. This means that a car ferry designed for these vehicles could carry them at much higher density and load them much faster, forwards or backwards, than conventional cars driven on and off by humans. Plus there are no clearances required for access

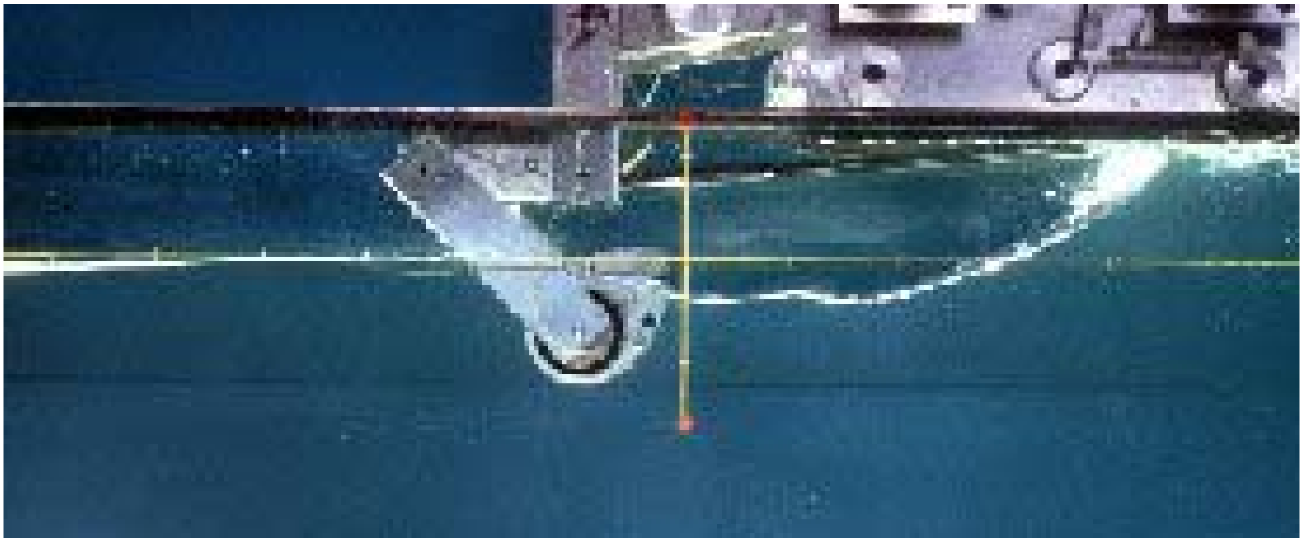


Figure 8

because the passengers are out of the cars before they are boarded.

Terminal Design

At least half the capital cost (and probably more than half of the operating cost) of the system is in the terminal, especially the breakwaters. Much of the environmental "cost" is in the terminal as well. An interesting strategy to minimize these costs is innovative design of protection systems. Floating breakwaters may have been discredited in the Bay Area by Pier 39, but this was a system that was widely predicted to be a failure by real ocean engineering professionals. (A wave barrier has to have a resonance frequency in the range of what it is intended to absorb, otherwise it is transparent.)

The authors would like to suggest that terminal breakwaters be designed to operate optimally in the band of wave energies between those that make boarding and other quayside operations dangerous and those that prohibit sailing at all (if you can't sail, there is no point in loading). In more severe sea states, the vessel can be moored off the quay where more motion is survivable. Determining the limits of boarding will require studies of the relative motions and accelerations of the ferry and the quay, and the limits of passenger movement, and the vessel motions induced by various sea states. (These limits might be extended by clever boarding system design. One of the authors worked on such systems for transferring between supply vessels and offshore oil platforms, and there are a number of interesting schemes.)

Once performance requirements of the breakwater are determined, then a floating system can be tuned to cover this band. Basically this simply requires that the ratios between the waterplane properties (area and moments of inertia) and the underwater volume be selected correctly. One very interesting option here is to use "Salter's Duck" as a component. This device is an egg shaped cylinder, with the point facing the waves. The Duck "nods" – pitches - with the point rising and falling. This absorbs and reflects wave energy, but since the down wave end is round, no energy in pitch is transmitted through the device. These devices absorb as much as 85% of the wave energy. However, what is really interesting is that the Duck was invented not for coastal protection, but for alternative energy – the Duck contains a generator powered by the nodding motion. This means the terminal protection would also provide power, possibly for lighting or other services. Though the use of these types of alternative energy schemes has always been limited by the capital cost compared to the value of the power they make, in this case we are saving the capital cost (and environmental impact) of a traditional bottom founded breakwater, and getting energy in addition. Even if the energy doesn't amount to much, the symbolism is huge. Figure 8 (Salter, 2006) shows a Duck being tested in a wave tank – note the amazing reduction in wave energy from the oncoming sea spectra (from the right).

Alternative Energy

A ferry system is highly localized and specialized. This means that a ferry system can be used to prototype and showcase alternative energy sources for propulsion as well as terminal services, though a public subsidy to cover the differential cost of such experiments is appropriate (note that the WTA is planning a fuel cell powered ferry as just this sort of demonstration).

Methane is available from biological sources through anaerobic decomposition of non-food plant materials and other biological sources – the City of San Francisco has a pilot program to generate methane from food wastes and animal feces, for example. Most plant material is long chain sugar polymers, but these molecules can be broken into glucose (cattle are outstanding in this field) and then decomposed to methane by bacterial processes, which could be warmed by solar energy. Though this requires collection systems that might have adverse impacts, it would also reduce methane now entering the atmosphere from agricultural waste. Since methane is a very powerful greenhouse gas, this might be a net benefit, but again, the whole system needs to be accurately evaluated.

The main problem of methane is that it is very bulky and the systems (which have to be at the terminal) to compress it to pressures at which storage aboard becomes feasible are potentially noisy, expensive and require energy. The authors have conceptualized a straw man 149 passenger ferry running 18 knots on two 600 horsepower engines for a variety of issues. If fueled twice a day on methane, (at 8 round trips per day) it would need 242 cubic feet of cylinders at 150 atmospheres. This is twenty each eight-foot by one-foot cylinders. A comparable liquid fuel rate would be 337 gallons per day, fuelling once. (And note that liquid fuel storage can be discounted against tonnage by storing it in tanks with deep frames, whereas this isn't practical for cylinders - lightening holes in deep tonnage frames can't line up.) Is this volume of fuel storage practical? Good question.

Methane can be used in existing Otto cycle spark ignited engines, but there is another interesting possibility: The Steam Augmented Gas Turbine, SAGT, was developed by the Navy in the '90s. This system uses the hot gas turbine exhaust to fire a boiler. The steam is then injected in the combustor where it is heated even more. This lowers the temperature in the turbine, which reduces the efficiency somewhat but also reduces the thermal load on the turbine blades, so they can be made of less exotic materials (it also reduces NOx emissions). However, picking up the waste heat in the gas turbine exhaust lowers the bottom end temperature of the cycle, which is much more effective in increasing thermal efficiency. The big gain is that mass flow through the turbine is increased without increasing compressor load, (which is parasitic on the system) or airflow. As a result, power produced in LM2500 turbines fitted with this technology was tripled and fuel consumption for typical DDG 51 service was reduced by almost 30%; Urbach (1994). There are numerous variants of this technology with various stages of intercooling and reheat, but it is worth exploring, especially since the lower limit of waste heat recovery temperature in conventional fuelled engines is based on the condensation temperature that would produce corrosive sulfur compounds. A methane fuel SAGT plant could "squeeze" its exhaust even harder for better efficiency. A ferry is an ideal platform for this technology as one drawback to SAGT aboard a warship is the weight of a reverse osmosis plant to produce the necessary injection water. A ferry would not need to carry this equipment – it could take on water as well as fuel. The technology of RO has also improved. One of the authors recently contacted vendors of such equipment and acceptable purity is now achievable in two pass rather than the three pass systems required a decade ago. One drawback to this system is that the steam produces a large visible plume, (which is a severe problem for a combatant). A ferry operator would have to be sure the public knew that the plume was steam, not smoke.

It is also worth noting in passing that more or less conventional steam is another candidate for gaseous fuels. Since a ferry can take on water frequently, it can use a once through system, exhausting steam to a direct contact condenser at very low temperatures. This also eliminates the steam engineer's least favorite device, the deareating feed heater. Feedwater can be deareated ashore, (possibly with solar heat) in a tower. The turbine can also be simplified. Radial inflow turbines are inexpensive, simple, very efficient at a single design point (though poor elsewhere), but a ferry runs at mostly constant power and speed. To add yet another choice, note that the Navy also has explored gas turbine heated steam either for additional shaft power or to run the first stage of air compression; (Marron 1981). Again, on a ferry, this could be very simple as it would be once through.

Another gaseous fuel is hydrogen. This can be used in turbines, fuel cells, or if pure oxygen is also available, in a direct steam generator with water injection into the flame. Hydrogen is even worse for storage, (unless new technologies based on chemical storage or absorption proves feasible). However hydrogen can be produced from solar energy and it is interesting to imagine a solar powered system to generate it just to see if it is at all even vaguely possible.

To just get a bound on the feasibility of some kind of solar power scheme, we explored solar heated magneto hydrodynamic (MHD) power. Though ultimately photovoltaics may be more efficient, the basic physics of MHD is easy to use to get an estimate. It is the same as any other heat engine, though instead of spinning a turbine, MHD works by passing a conductive fluid through a magnetic field. Most MHD systems use hot gases from burning fossil fuels, generally with an additive to increase conductivity. This means that they are essentially a bladeless gas turbine, but they still have to have a compressor and the resultant losses. However, a solar system can use boiling mercury instead, since it is highly conductive (thereby eliminating the need for super conducting magnets – MHD power density increases directly with fluid conductivity and with magnetic flux density squared).

Liquid mercury is pumped onto a porous heat-absorbing medium (graphite powder, for example) in a cavity illuminated by a reflector shining through a high temperature lens. The mercury boils and the hot vapor expands through a nozzle. The rapidly moving vapor passes through a magnetic field and electric current is generated in pickups on the nozzle walls. At the end of the nozzle a chamber with cooling coils condenses the mercury back to a fluid. This is just a steam engine with a funny turbine and can be readily analyzed, at least to a back of the envelope level, by classical thermodynamics, a mercury properties table and just a bit of magneto hydrodynamics. Something similar could be done with regular water steam turbines, but MHD (both as turbine and as pump) allows a sealed system with no moving parts, (except a fan or water pump to cool the condenser) which is attractive.

The bottom line is that a mercury MHD plant running between 329 F and 1390 F would be able to achieve about 43% overall efficiency or a bit better. (These calculations are left to the reader and will appear in the quiz.) Based on standard figures for sun tracking reflectors at 38 degrees latitude, the raw solar input is about 3 MW hours per square meter of reflector per year, yielding about 1.3 MW hours per square meter per year. The same straw man ferry as above, counting losses due to electrolyzing water, compressing hydrogen, and a fuel cell aboard will require about 100 reflectors, each five meters in diameter. This would take up a collector field of about 2 acres, or the equivalent area of a parking lot for 270 cars.

Assuming each dish and an allocated portion of the compression and storage system is $15,000, plus land and maintenance, gives energy cost equivalent to diesel fuel at a bit over $3.00 per gallon. With still more shaky assumptions, the energy cost of a round trip ticket is about two dollars, roughly a dollar more than a diesel powered craft. Obviously this cost probably is wrong by a good deal, but it is unlikely to be less. Is this cost differential acceptable?

Another scheme uses *Botryococcus Braunii* (Yen, 2000) or other descendants of algae thought to be originally responsible for making crude oil (Miyamoto, 1997). This algae makes about 40% of its dry weight as lipids and long chain hydrocarbons which can be processed into fuels. Assuming that the parking spaces are covered with panels full of algae covering 300 vehicles (only the vehicles – assume a double row of facing roofs), you could get 400 barrels of crude oil equivalent per year, reducing about 120,000 lbs of carbon emissions, and probably sequestering another 60,000 in waste cell material. This algae is also denitrifying, so it can use sewage as a feedstock and reduce nitrate pollution.

Are there any adverse impacts to planting solar dishes filled with mercury steam or roof panels full of sewage all over the parking lot? Should society subsidize ferry riders using solar energy directly? How much? Are the authors totally out in left field with these analyses? All good questions which are left to the reader as well, but it does suggest that there may be something to some kind of solar scheme in the long run, as well as its limits.

CONCLUSIONS

"God intended people to travel by ship"
Cedric Ridgely-Nevitt

- Ferry systems are economically and politically justified even with substantial subsidy, but system designers have a duty to make sure that the systems are as cost and environmentally effective as possible.
- Passenger capacity (especially over 149 passengers) and speed need to be very carefully considered and justified. Both are expensive, and other approaches may be less expensive and more effective in attracting riders and protecting the environment.
- Environmental issues need to be very carefully analyzed, looking through the whole lifecycle of and supply chain of a system. Simple answers can do more harm than good.
- The intermodal portion of the system is at least as important as the marine portion and probably more so.
- The construction of ferries in the region served is a worthwhile goal and is feasible, even in a high wage area by using both established and innovative techniques for modern shipbuilding.
- There are numerous innovations, some silly, others worthwhile, and some appearing to be one while actually the other. The authors have thrown out a few and leave it to the readers to judge which category they fall in, but the point is that there are a lot of ideas out there and marine professionals need to contribute their own, and be open to those of others. However, it is important to understand which are for now and which are for later, and to avoid making too many promises.
- All naval architects are familiar with the design spiral, but in the case of a ferry, the ship design spiral is an inner loop in the system design spiral and there is a lot of opportunity to optimize system design in the interaction between the ships and the rest of the system. This implies that ship design studies should come early and often.
- The Society of Naval Architects and Marine Engineers needs to become much more prominent and visible in ferry design and overall system design issues, especially as regards the interaction of system design and vessel design. SNAME needs to be a leading voice, ready to advise those interested in these opportunities.
- Finally, individual marine professionals need to be alert to ferry system proposals at an early stage, especially those involving public funds, and to participate. It is our duty, both as engineers and as citizens, to contribute our expertise in appropriate public forums.

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The opinions expressed in this paper are those of the authors and do not necessarily reflect the opinions or official policy of the Coast Guard or the Department of Homeland Security.

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APPENDIX A

BTU/passenger-mile: Notes on the relative energy efficiency of ferries, cars, busses and trains

There are several ways to calculate the fuel efficiency of a transit vehicle. Power can be measured at the engine flywheel, at the propeller or at the wheels, or as the chemical energy of the fuel consumed. Passenger-miles can be determined using any one of several assumptions about load level or the overhead of deadheading. For this analysis, BTU/passenger mile is based on the chemical energy of the fuel, approximated as 17,500 BTU/lb or 140,000 BTU/gallon for all liquid fuels. For diesel engines, a fuel rate of 0.35 lb/hp-hr is assumed.

Passenger loading for a commuter ferry, bus or train is assumed to be 50%, allowing for less then full passenger loads in the commute direction and very low passenger loads in the "reverse commute" direction. Home porting strategies can reduce the number of reverse commute runs, but this is offset by light passenger loading during mid-day service.

Single-occupancy car:
7,000 BTU/pax-mile
(assuming 20 MPG and 140,000 BTU/gal)

AC Transit Bus:
660 BTU/pax-mile one-way with 56 passengers
1,320 BTU/pax-mile at average 50% load.
(from http://www.watertransit.org/pubs/eir/Section3.13_Energy.pdf)

Light Rail
91 BTU/pax-mile, full passenger load
182 BTU/pax-mile, 50% load.
(from http://www.watertransit.org/pubs/eir/Section3.13_Energy.pdf)

BART
68 BTU/pax-mile, full passenger load
136 BTU/pax-mile, 50% load
(from http://www.watertransit.org/pubs/eir/Section3.13_Energy.pdf)

Ferries currently in service between the East Bay and San Francisco
"Peralta" - 3200 HP, 26 knots, 331 passengers
2,280 BTU/pax-mile, full passenger load
4,560 BTU/pax-mile, 50% passenger load

"Encinal" - 3600 HP, 24 knots, 388 passengers
2,370 BTU/pax-mile, full passenger load
4,740 BTU/pax-mile, 50% passenger load

"Bay Breeze" - 1285 HP, 26 knots, 250 passengers
1,210 BTU/pax-mile, full passenger load
2,420 BTU/pax-mile, 50% passenger load

"Express II" - 850 HP, 28 knots, 149 passengers
1,250 BTU/pax-mile, full passenger load
2,500 BTU/pax-mile, 50% passenger load

Historical:
Ferry "Berkeley" (1889) - 1250 HP, 12 knots, 1700 passengers
536 BTU/pax-mile, full passenger load
1,072 BTU/pax-mile, 50% passenger load (assuming fuel rate of 0.5 lb/hp-hr)

Proposed:
New design based on "Express II" with maximum speed 20 knots:
640 BTU/pax-mile, full passenger load
1,280 BTU/pax-mile, 50% passenger load (Reducing fuel consumption/mile by square of speed ratio.)

New design based on "Express II" with maximum speed 18 knots:
515 BTU/pax-mile, full passenger load
1030 BTU/pax-mile, 50% passenger load (Reducing fuel consumption/mile by square of speed ratio.)