PART 6
FERRY CAPACITY

CONTENTS

LIST OF EXHIBITS

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CHAPTER 1. FERRY CAPACITY

INTRODUCTION

Ferry service plays a major role in urban transportation systems in many North American cities such as New York, San Francisco, Seattle, and Vancouver. Ferry transit provides an alternative to cross water barriers that would otherwise necessitate expensive infrastructure that may not be feasible to construct. Ferry transit corridors can also offer direct access to residential and business areas and can potentially reduce the transit travel time that would otherwise be experienced in mixed traffic.

There is currently little information regarding waterway system- or vessel-related capacity. Ferry operators are stimulating discussion in this area, but it remains a facet of waterway capacity that is relatively undeveloped.[R3] The objective of Part 6 is to build an initial framework for determining the capacity of ferry transit services in North America.

Ferry system capacity is a relatively undeveloped topic.

This chapter is arranged in three primary sections: an overview of ferry facilities and service that affect capacity, a methodology to calculate vessel capacity, and a methodology to calculate passenger capacity.

FERRY FACILITIES AND SERVICE

Ferry Service

The type of ferry service provided by different operators can vary significantly. Some operators may provide passenger service with short trip lengths, relatively high frequencies, and a number of stops. Other ferry services may accommodate passengers, and possibly their autos, on trips with only one origin and destination. Ferry capacity evaluations must consider these different service configurations.

A breakdown of typical ferry types is provided below:

- *Water Taxis:* small watercraft that typically serve short cross-waterways or waterway circulation routes;
- *Passenger Ferries:* larger vessels that have higher passenger capacity and speeds than water taxis and typically serve short- to moderate-length routes; and
- *Auto Ferries:* also known as roll-on, roll-off ferries, these ferries transport vehicles as well as passengers. They are typically used on longer routes across major bodies of water and on low-volume rural roads crossing rivers.

By definition, a water taxi provides on-demand service to a variety of destinations. However, the term is commonly applied to small watercraft serving multiple-stop routes.

Exhibit 6-1 illustrates the different service types. A breakdown of some of the characteristics of U.S. and international ferry service is provided in Exhibit 6-2. A more comprehensive list of ferry service providers can be found in Part 2.

Because ferries can only take passengers to the water's edge, intermodal transfers are usually required at one and often both ends of the ferry trip. Options for providing this transfer include park-and-ride lots, feeder bus service, roll-on, roll-off bus service (for auto ferries), and terminals located close to rail service (as in New York and San Francisco).

Intermodal transfers are usually required at one or both ends of ferry trips.

Exhibit 6-1
Ferry Service Type Examples

(a) Water Taxi (Baltimore)

(b) Auto Ferry (British Columbia)

(c) Passenger Ferry (San Francisco)

(d) Passenger Ferry (Boston)

Exhibit 6-2
Examples of U.S. and International Ferry Service Characteristics

Location	Service	# of Vessels	# of Terminals	# of Routes	Peak Frequency (min)	Annual Riders (000)
Ft. Lauderdale	Water taxi	4	36	1	On-demand	300
Sydney	Passenger	27	29	10	15-30	13,000
Hong Kong	Passenger	86	19	19	10	30,000
San Francisco	Passenger	12	9	6	30, 45+	3,500
Seattle	Auto, Passenger	26	20	10	30-40	25,000

Vessel Type

Vessels can be categorized by their physical and mechanical characteristics. Physical characteristics include the hull type and vessel dimensions and affect the design of both the vessel and passenger facilities. The Society of Naval Architects and Marine Engineers has prepared a summary of a variety of hull types:(R1)

- *Monohulls* are commonly used in the United States, especially where speeds greater than 30 knots in high sea conditions are not required. The semi-planing monohull represents a low capital cost, low maintenance option for relatively protected waters.
- *Catamarans* have steadily eclipsed other hull forms as the choice of most ferry operators for all but very high-speed (greater than 40 knots) service. The catamaran offers a more stable platform than the monohull, greater maneuverability (owing to widely spaced propellers), low draft requirements at a given hull displacement, and reasonable economy of operation. Compared with monohulls of similar size, however, capital costs are higher and wider vessel berths are required. At low speeds, operating inefficiency increases, which also increases fuel consumption and fuel costs. Water jet propulsion combines relatively good fuel economy with speed and passenger comfort.

- *Hydrofoils* feature low-wake profiles, high speed, and low fuel usage. They have deep draft requirements and are susceptible to disablement by submerged or floating flotsam. Debris impacts can lead to costly and time-consuming dry-docking.
- *Small Waterplane Area Twin Hull (SWATH)* vessels are designed to reduce vessel motions during rough head seas, while sustaining normal cruising speeds. SWATH ships typically have two submarine-like lower hulls completely submerged below the water surface. Above water, a SWATH resembles a catamaran.
- *Surface Effect Ships* are propelled through the water with 85% of the hull weight lifted out of the water. These ferries operate with low fuel usage and high speeds but have a high capital cost per seat, high maintenance requirements and costs, susceptibility to speed loss in heavy sea conditions, and a less comfortable ride.
- *Hovercraft* travel above water and are propelled through the air. This hull form is attractive for shallow areas (since the vessel travels above the water and not through it) and is faster than other vessels (since it has little contact with, and hence little friction from, the surface water). For short distances, these vessels can also operate across land to sites. Negative considerations include high capital and maintenance costs, bumpy rides, and high levels of exterior noise. As of 2003, with the exception of a single vessel in the St. Petersburg, Florida area, no commercial hovercraft operate in U.S. waters today, although many operate in Europe.

Exhibit 6-3 illustrates the common North American vessel types.

Exhibit 6-3
Vessel Types


(a) Monohull (Seattle)


(b) Catamaran (Sydney, Australia)

Vessels' mechanical properties, such as propulsion, will affect the vessels' speed and the resulting travel time over a route. Types of propulsion include fixed pitch propeller or controllable pitch propeller, which are common to monohull vessels; water jet, which is common to catamarans; and cable. Some smaller vessels may also be propelled by outboard motors. Some new ferries employ a "cycloidal propulsion" system. Instead of conventional propellers and rudders, power is obtained from two vertical cycloidal propulsors, one at each end of the boat. This technology allows the ferry to make 360-degree turns or to move sideways with no forward or backward movement.

Examples of vessel types and characteristics are provided in Exhibit 6-4.

Exhibit 6-4
Examples of Vessel Types and Characteristics (2002)

Operator	Water Body	Service Type(s)	Number of Vessels by Type	Passenger Capacity	Speed (Knots)
New York City DOT	Harbor	Passenger	Monohull (5)	1,200-6,000	16
		Auto Ferry	Monohull (3)	3,500	16
Texas DOT, Port Aransas	Channel	Auto Ferry	Monohull (6)	100	10
Seajets, Palm Beach, FL*	Coastal Ocean	Passenger	Hydrofoil (2)	280	46
Blue & Gold Fleet, San Francisco	Bay	Passenger	Monohull (7)	200-700	12-15
Washington State Ferries, Seattle	Puget Sound	Passenger	Monohull (2) Catamaran (5)	250-350	25-35
		Auto Ferry	Monohull (24)	550-2,500	10-18
Hover-USA, St. Petersburg, FL	Bay	Passenger	Hovercraft (1)	17	30-35

*ceased operation in 2001

A vessel's capital and operating costs will ultimately affect the fare and, hence, the passenger demand. Generally, the power required to propel a vessel increases at a more rapid rate than does its speed. It is common for fuel consumption to double as speeds increase from 25 to 30 knots. This fuel consumption can easily increase operating costs by $100 per hour—requiring fare revenues from 20 to 40 additional passengers, or a higher fare, which may also influence demand. The paradox of this fuel consumption curve is that higher speeds make little difference in overall travel time on short routes. For example, the difference between a 25-knot vessel and a 30-knot vessel on a 7-mi (12-km) route would be about 3 minutes in travel time.[R2]

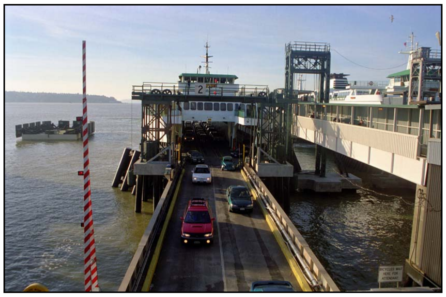
It may be feasible to initiate service on shorter routes with vessels operating at speeds down to 25 knots (30 mph or 50 km/h) if terminals are designed to maximize loading and unloading efficiency to make the total travel time competitive with driving. Although the associated costs, and hence the fares, are not within the scope of this manual, they will ultimately impact the passenger volumes and hence the achievable capacity of a ferry transit system.

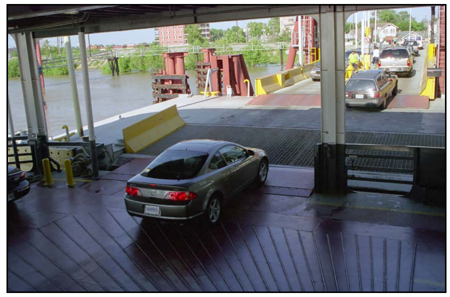
Docks and Loading Facilities

Docks

Docking configurations will largely depend upon the vessel. Auto ferries are typically end-loaded and hence have dock facilities that accommodate this process, as illustrated in Exhibit 6-5. Departing vehicles are stored at the landside or dockside vehicle staging areas. Passenger ferries are typically side-loaded, which can be accommodated by parallel or linear berthing facilities. The most typical dock design has parallel berths, such as those found at Sydney's Circular Quay. Some dock facilities may have a variety of berthing arrangements to facilitate a range of vessel types.

Exhibit 6-5
Examples of Auto and Passenger Ferry Dock Configurations


(a) End Loading (Seattle)


(b) Side Loading (New Orleans)


(c) Side Loading (San Francisco)


(d) Side Loading (Sydney, Australia)

Vehicle Staging Area

A critical aspect of an auto-ferry facility is its ability to accommodate vehicle loading and unloading. A number of North American auto-ferry operators request that auto-passengers on longer-distance routes make reservations and/or arrive 30 minutes to 3 hours prior to departure. The suggested arrival time is a function of the anticipated demand and may include time for security and/or hazardous material checks. For services between Canada and the United States, the advance time may also include customs checks.

The process of vehicle loading and unloading is time consuming and hence requires adequate access facilities and circulation provisions at the terminal. One of the key facilities in this process is the vehicle staging lot. This area allows for the storage of queuing vehicles, and a smooth transition between embarking and disembarking vehicle movements. The staging areas can be located dockside or landside. A plan sketch of a typical landside staging area is shown in Exhibit 6-6 and examples are shown in Exhibit 6-7. The various components of staging areas are described below.

Exhibit 6-6
Vehicle Staging Area Diagram

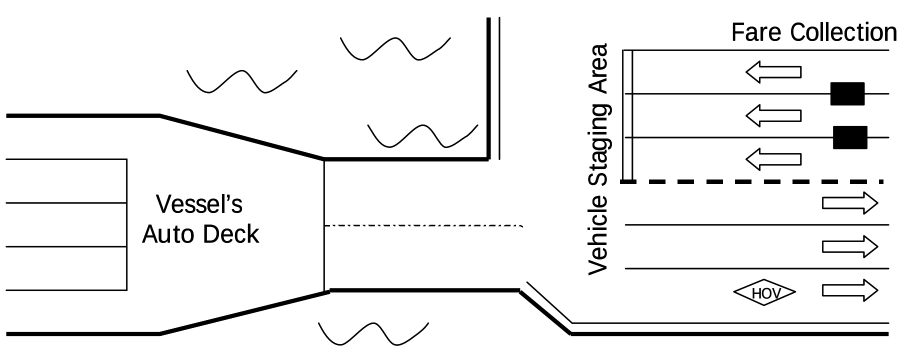


Exhibit 6-7
Vehicle Staging Area Examples

(a) Seattle

(b) Bar Harbor, Maine

Vehicle Embarking

The staging lot design for embarking passengers will depend upon a number of factors. These include the following:

A vessel's capacity to transport vehicles is measured in auto equivalent units (AEUs) that reflect the amount of space used by each vehicle type.

- *Vessel auto-deck capacity:* Because the auto deck size varies considerably from one vessel to another, the concept of Auto Equivalent Units (AEUs) is commonly used to measure auto-deck capacity. Different vehicle types are weighted based on the space they occupy compared to a standard automobile. For example, the typical factor for a recreational vehicle, single-unit truck, or bus is 3, and the factor for a semi-trailer truck is 5. It is important to consider the average fully loaded volume, as some vessels may have adjustable platform decks that can be fully or partially utilized on a given sailing. If the average fully loaded sailing holds 10 autos, 5 RVs, 5 buses, and 10 semis, then the capacity is 10x1 + 5x3 + 5x3 + 5x5 = 65 AEUs.

Staging areas can be used to organize vehicles by size, weight, and destination prior to loading.

- *Loading process:* In order to keep the vessel balanced while vehicles are loaded, and to make sure that other vehicles do not block vehicles disembarking at intermediate stops, some agencies carefully manage the order of vehicle loading from the staging area. Vehicle loading will usually take place under the supervision of experienced crewmembers that are directed by the Chief Officer or Mate of the vessel. For these same reasons, vehicles that are first to board the ferry are not necessarily the first to disembark. The staging area should be designed to allow the flexibility of vehicle choice or, alternatively, staff should be available to assign vehicle types to a particular queuing bay. In some cases, such as the Lake Michigan Carferry, vehicles are loaded and unloaded by crewmembers or staff only.

The size of the staging area should, at a minimum, be sufficient to accommodate the vessel auto-deck capacity. However, an overload factor should be considered to accommodate excess vehicle demand. Washington State Ferries uses an overload factor between 1.3 and 2.2 depending on scheduled ferry headways, plus an additional two lanes for emergency and high-occupancy vehicles.

Well-designed vehicular circulation paths, with suitable signing and striping (e.g., lane numbers), are important to ensure the safe and efficient flow of traffic through the staging area. Barriers or traffic cones are often used to close off any temporary excess queue storage, so as to better define the vehicle path.

Fare Payment

Vehicle arrival patterns tend to be related to whether a particular sailing usually has excess capacity or not.

Fare payment and ticket collection practices vary depending upon the type of service. At larger ferry terminals, the fare may be collected at booths prior to entering the staging area. Smaller terminals may adopt a less formal process where the fare is purchased from staff roaming through the vehicle staging area or from a crewmember aboard the vessel. Persons traveling with their automobiles tend to adjust their behavior depending upon the demand for the service. That is, if a vessel typically has excess capacity, vehicles will arrive just before a vessel's departure. Hence, there will be a short period of high vehicle arrival volumes that may require a number of staff or ticket booths. Alternatively, if a given sailing is frequently over capacity, motorists will arrive early and there is less need to have high-capacity fare collection facilities.

Vehicle Disembarking

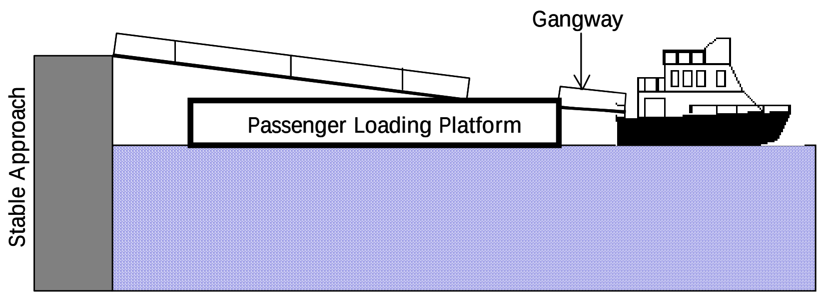
The disembarking process is commonly a straight path from the vessel auto-deck to serve vehicles in a timely manner. Some urban ferry terminal designs include special features, such as HOV lanes that feed into the urban street system.

Passenger Loading Area

To achieve minimum travel time, there must be maximum efficiency in loading and unloading passengers at the terminals. This will generally require standardized design criteria for both passenger platforms and vessels. It is also recognized that design should be a function of the peak throughput of passengers.

Passenger loading areas are generally located on a floating platform or stable approach (e.g., facilities supported by pilings), as illustrated in Exhibit 6-8. The passenger loading area also includes the gangway (between the vessel and the loading platform) and walkway facilities (between the shore and the loading platform) that accommodate loading and unloading.

Exhibit 6-8
Elements of Ferry Passenger Loading



The loading area design may vary considerably. Some examples are provided below and are illustrated in Exhibit 6-9:

- *Brisbane (Australia) CityCat:* Loading occurs from a floating platform (some covered, some not) approximately 110 ft² (10 m²) in area. Passengers first disembark from a single 3-ft (1-m) wide manual gangway. When all passengers have disembarked, passengers may then embark. Fares are collected by a combination of an on-board cashier (for those paying cash), and an on-board ticket-validating machine (for those holding multiple-ride tickets and passes).
- *Sydney (Australia) Ferries:* Passenger loading at Circular Quay occurs from a large covered floating platform, which blends seamlessly from the terminal. Passengers pay their fares prior to entering the platform area. The facility design allows passengers to disembark using the upper-deck gangway, while other passengers simultaneously embark on the lower-deck gangway. The disembarking movement is connected to a fenced walkway that leads directly into the terminal.
- *Golden Gate Ferries (San Francisco):* Passenger loading occurs from a covered fare-paid area. Passenger loading occurs via one (monohull vessel) or two (catamaran) wide gangways. The latter configuration can serve hundreds of peak-direction passengers in minutes.

- *SeaBus (Vancouver)*: Gangways are located on both sides of the vessel. Passengers are unloaded from one side and loaded on the opposite side. This configuration allows the 400-passenger vessels to be loaded and unloaded within 90 seconds.

Exhibit 6-9
Examples of Passenger Loading and Unloading

(a) San Francisco (Ferry Building)

(b) San Francisco (China Basin)

Passengers visible against the far wall in picture (c) have just disembarked the vessel from its opposite side.

(c) Vancouver

(d) Vancouver

(e) Brisbane, Australia

(f) New Orleans

There are a number of safety concerns at the platform:

- *Height difference between the stable approach and the water:* The stable approach to a passenger boarding facility is typically high enough above average water level to prevent submergence in all but the most extreme conditions. The height of the stable approach can range from several feet to over 20 feet (1 meter to over 6 meters), and is based on historical data.
- *Water level changes:* All waterfront facilities experience changes in the height of the water relative to the stable approach. Coastal facilities undergo tidal cycles, with normal ranges from little more than 1 foot to over 20 feet. Non-tidal (inland) facilities experience water level changes less frequently, as the result of rain, snowmelt, dam releases, and so forth, which tend to occur in predictable patterns. However, the changes can sometimes be more severe, with ranges in excess of 20 feet (6 meters). Extreme weather conditions can add considerably to the range at all facilities.

- *Height difference between passenger loading platform and the vessel:* When a loading platform (dock) is in the pathway between the stable approach and the vessel, the freeboard difference between the dock and the vessel is an access barrier. Because freeboards of docks and vessels vary greatly, there will be widely varied and unique height differences for dock-vessel combinations. This height difference may also vary for a particular dock-vessel pair, depending on loading and weather conditions.(R4)

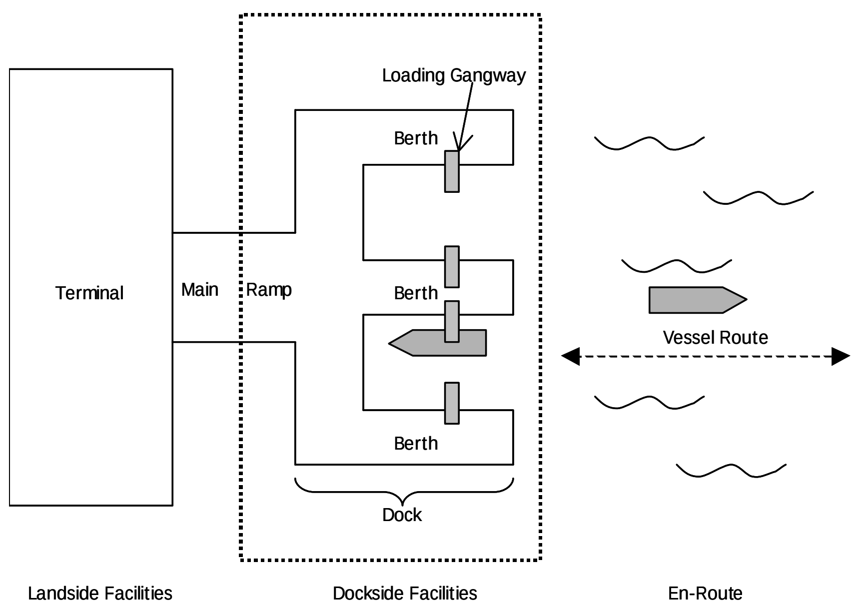
Safety features to accommodate these conditions should include:

- *Guardrails:* Guardrails are critical to ensuring passenger safety because of the inherent dangers of accidentally leaving the path of travel at a marine facility.
- *Edge treatments and detectable warnings:* Tactile edge treatments and detectable warnings for the sight-impaired are important in ensuring passenger safety.
- *Changes in slopes, heights, materials, and so forth:* The path of travel from land to vessel is likely to have frequent changes, particularly slopes. Changes in the height of the loading platform relative to the shore or the vessel, due to tides or fluctuations in river level, will need to be accounted for. Attention to the slope of the ramp must be made for passengers with disabilities.
- *Non-slip surfaces:* Most areas at a marine facility will periodically get wet or damp from water spray. The wide use and application of non-slip surfaces is important for passenger safety.
- *Assistance:* Assistance by crew for all passengers in the marine environment is standard practice due to the environment's dynamic nature. This positive tradition in the industry will be a part of the growing need for access for persons with disabilities.

VESSEL CAPACITY

Vessel capacity can be calculated for two key locations: berth (or loading area) and dock facility. A route's vessel capacity will be constrained by the lowest-capacity dock facility along the route. These locations are depicted in Exhibit 6-10.

Exhibit 6-10
Vessel Capacity Measurement Locations



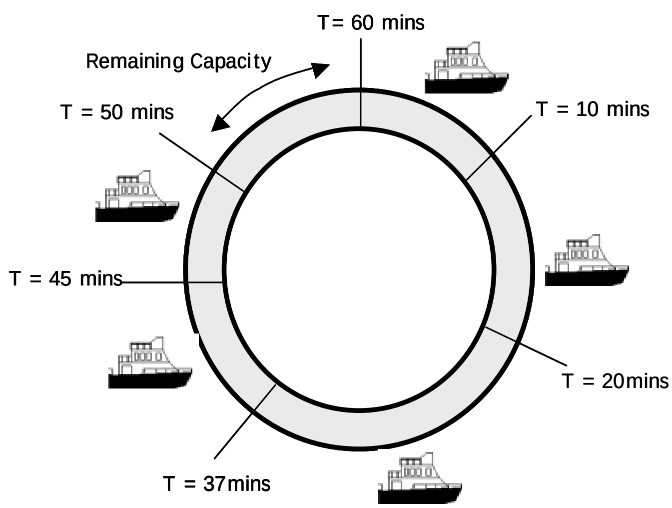
The berth, or loading area, encompasses the passenger loading platform, the gangway connecting the platform to the vessel, and any walkway facilities connecting the platform to a waiting area or the shore. The dock facility is composed of one or more berths.

Within a given hour, a ferry berth may accommodate multiple vessels. Given that each vessel uses a portion of the hour to serve passengers and/or autos and clear the berth, only a limited number of vessels can access the berth in the hour. The vessel capacity of a ferry berth is defined as the maximum number of vessels per hour that can use the berth at a given level of passenger demand.

Quantifying loading time is important even when vessel capacity is not an issue.

Ferry operators can determine how the current or planned vessel demand compares to the vessel capacity of the loading facilities, as illustrated in Exhibit 6-11. When a facility operates close to its capacity, any operating irregularities will cause delays to vessels, as they will arrive at the berth only to find it occupied by another vessel. In addition, when a facility operates close to its capacity, any growth in demand will increase each vessel's service time, and thus reduce the time within the hour available to other vessels. In this case, measures may be implemented to decrease the vessel loading and clearance time, or ultimately construct an additional berth.

Exhibit 6-11
Berth Vessel Capacity



In situations where vessel capacity is not anticipated to be an issue, quantifying the loading time enables planners and ferry operators to estimate a new route's travel time and to isolate any design issues related to the loading facilities.

The vessel capacity of the dock facility is a function of the capacity of the individual berths. The following sections present an overview of the primary factors that determine vessel capacity at each of these locations.

Berth Capacity

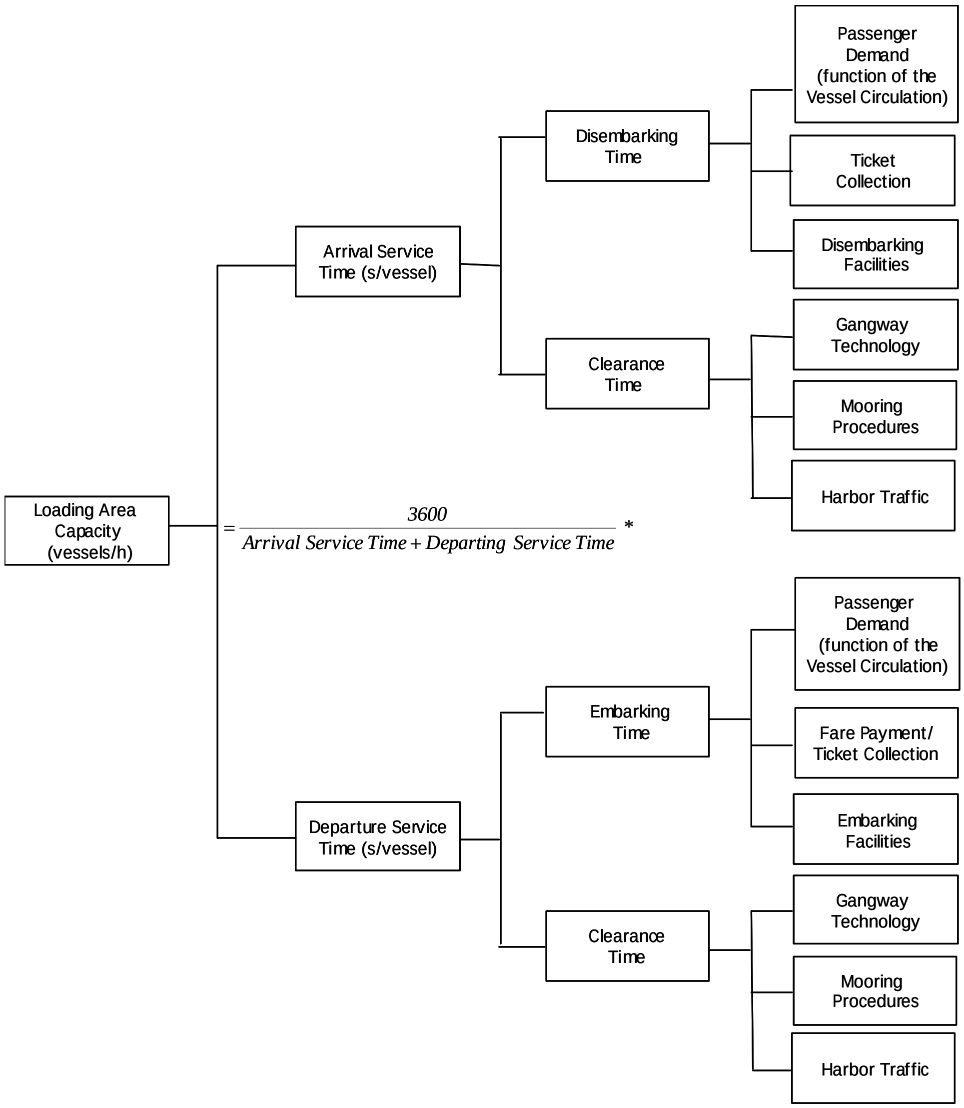
The vessel capacity of the berth, or loading area, is dependent upon two key components: the arrival service time and the departure service time. Arrival service time, given in seconds per vessel, is the sum of the vessel clearance time, plus the passenger disembarking time. Similarly, departure service time is the embarking time plus clearance time of the vessel to allow for other vessels to use the dock area.

Simultaneous passenger loading and unloading.

Disembarking and embarking time is a function of a number of factors, including passenger or auto demand, fare collection methods, and the design of the embarking and disembarking facilities, such as the dimensions of the gangways and walkways. The vessel and loading design may also enable the embarking and disembarking times to be overlapped.

The clearance time is the average time from when one vessel is ready to leave the berth to when another vessel is able to use the berth. A portion of the clearance time will be made up of the time for the vessel to maneuver out of and clear the berth area. Other factors include the gangway technology, mooring procedures, and the influence of any harbor traffic. These factors are illustrated in Exhibit 6-12 and described in more detail below.

Exhibit 6-12
Berth Capacity Factors



*Facilities may allow for the overlap of passenger disembarking and embarking, which should be accounted for accordingly.

Disembarking/Embarking Time Factors

Passenger or Auto Demand

The passenger or auto volume at a vessel's busiest entrance will control the service time.

The passenger (auto) demand is measured using the embarking and/or disembarking volume at the busiest entrance to each vessel, as this volume will control the total time needed to serve all passengers. Unless a vessel and its berth are designed to accommodate multiple gangways, this demand will be the same as the total passenger (auto) demand. For larger passenger vessels, passenger embarking and disembarking may occur simultaneously. In this case, the greater of the embarking or disembarking volume at the busiest entrance should be used to determine the loading time.

Fare payment does not affect passenger service time when fares are collected at the entrance to a fare-paid passenger waiting area.

Fare Payment

Fare payment and ticket collection procedures vary considerably in the ferry transit industry. At lower-volume terminals, passenger and auto fares are often collected at the gangway or on-board. Services that make multiple stops may also wish to collect fares on board to minimize or eliminate the need for staff at each dock. Depending on the number of bills and coins involved in paying cash fares and the potential need to issue a receipt, the time to serve each embarking passenger may be considerable. During peak tourist times on an Australian ferry, for example, fare payment has been observed to delay a vessel's departure at busy stops, as the line of passengers waiting to pay a cash fare to the on-board cashier can extend back onto the loading platform.

At larger terminals, fare payment and collection occurs in the terminal building, at the entrance to a fare-paid waiting area. Payment can be made to cashiers or through the use of ticket/token machines and fare gates. Automobile fare payment will typically occur at booths prior to entering the staging area. In either of these cases, fare payment does not affect the embarking or disembarking time.

Embarking and Disembarking Facilities

The stability and pedestrian-friendliness of the loading facilities affect the passenger disembarking and embarking time. These times also include the time to transverse the loading area facilities, which is a function of the length and width of the access walkway/roadway, and the boarding ramp or gangway.

Clearance Time Factors

- *Gangway Technology:* The gangway technology will affect the time it takes to place and remove the gangway. There are a number of current technologies:
    - Hand winch or manually placed;
    - Electric;
    - Hydraulic; and
    - Bow Loading, which offers the advantage of faster mooring and loading; however, terminals need to be configured for this system.
- *Mooring Procedures:* Mooring procedures vary considerably. Some examples are described below:
    - *Blue & Gold Fleet (San Francisco):* A three-step process involving fixing the spun line, bell line, and stern line. The mooring time is approximately 1 minute.
    - *Golden Gate Ferries (San Francisco):* The stern line is fixed and the vessel is left running to maintain tension. The 2-ton gangways rest upon the vessel to keep the vessel in place. This process takes approximately 30 seconds to complete.
    - *Staten Island Ferry (New York):* The vessel is docked with a rack system that guides the vessel. The lower-level gangway is attached with mooring hooks and the upper- and lower-level gangways are then placed on the vessel.
- *Harbor Traffic:* Small pleasure craft and windsurfers can cause delays to ferries, particularly on weekends. These conditions may result in congestion or a high-risk environment, forcing vessels to reduce travel speeds. In some cases, local authorities enforce the burden on a certain direction of travel. This means that the vessels traveling in a certain direction must yield to those vessels traveling in the other direction.

Other clearance time factors may include policy issues such as the time for staff to complete safety checks.

Berth Vessel Capacity

The maximum number of vessels per hour that a berth can accommodate, based on a given passenger demand, is given by the following expression:

Equation 6-1

$$V_b = \frac{3{,}600}{t_v}$$

where:

V_b = vessel capacity of the berth (vessels/h);
3,600 = the number of seconds in 1 hour; and
t_v = vessel service time (s/vessel), from Equation 6-2.

The service time is given by the sum of the clearance time and the embarking and/or disembarking times. An allowance for variations in embarking and disembarking times is also included, similar to the operating margin used in the bus capacity procedures presented in Part 4. This margin is based on two factors:

- *Coefficient of variation of the embarking and disembarking time* (c_v): the standard deviation of the loading/unloading time divided by the mean loading/unloading time.
- *Standard normal variable* (Z) corresponding to a desired failure rate (i.e., the probability that one vessel will arrive, only to find the previous vessel still occupying the berth), as given in Exhibit 4-6.

No default values are currently available for ferry capacity parameters; field data collection is suggested.

Discussions with various ferry operators suggests that commuter embarking and disembarking has very little variation, while tourist services experience significant variation around the mean. There are currently no ferry-related data that allow a default coefficient of variation to be given; however, one could determine this parameter from a series of field observations. Similarly, no data are currently available to provide a default clearance time; however, one could be determined from observations of current operations or from discussions with vessel captains.

If capacity will not be an issue, but it is desired to know the average time a vessel will occupy the berth (e.g., for use in estimating travel time), the operating margin (the Zc_vt_{ed} component of Equation 6-2) can be omitted.

Equation 6-2 provides the full berth service time equation.

Equation 6-2

$$t_v = t_{ed} + Zc_v t_{ed} + t_c$$

where:

t_v = vessel service time (s/vessel);
t_{ed} = average total embarking and disembarking time (s/vessel);
t_c = clearance time (s/vessel);
c_v = coefficient of variation of the embarking and disembarking time; and
Z = standard normal variable corresponding to the probability that the embarking and disembarking time will be more than c_v percent longer than average, from Exhibit 4-6.

Determining the disembarking and embarking times requires field measurements, or estimates of the number of embarking and disembarking passengers or automobiles. The following sections describe how to estimate these times when field data are unavailable, based on passenger demand, terminal and vessel design elements, and fare collection procedures. These procedures draw from the pedestrian flow procedures presented in Part 7 of the TCQSM.

Sequential Passenger Disembarking and Embarking

This section applies to situations where passengers disembark from the vessel and have cleared all walkways before passengers are allowed to embark. The service time elements in this process are as follows:

1. Passenger time to disembark the vessel over one or more gangways. This time is related to the number of gangways, the gangway width, and the passenger demand.
2. Disembarking passenger time to traverse the walkway to the dock exit. This time is related to the walkway width and the rate at which passengers exit the gangway(s).
3. If disembarking passengers arrive at the dock exit at a faster rate than the exit can process them, there will be additional delay at the exit. This could be an issue if the exit was narrower than the walkway leading to it, or if a doorway or exit gate is involved.
4. Once disembarking passengers have cleared the area, embarking passengers are allowed from the waiting area onto the walkway leading to the vessel. Entrance to the walkway could be controlled by a door, sliding gate, or other mechanism, any of which will have an associated time to serve all of the passengers in the waiting area. If fares are collected at the waiting area exit, this time should be included in the service time.
5. Embarking passenger time to traverse the walkway to the vessel. This time is related to the walkway width and the rate at which passengers exit the waiting area.
6. Time to board the vessel over its gangway(s). If passengers arrive at the gangway(s) at a faster rate than they can be processed, there will be additional delay at the gangway. If fares are collected at the gangway, this time should be included in the service time.

The total embarking and disembarking time is given by the following expression:

Equation 6-3

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

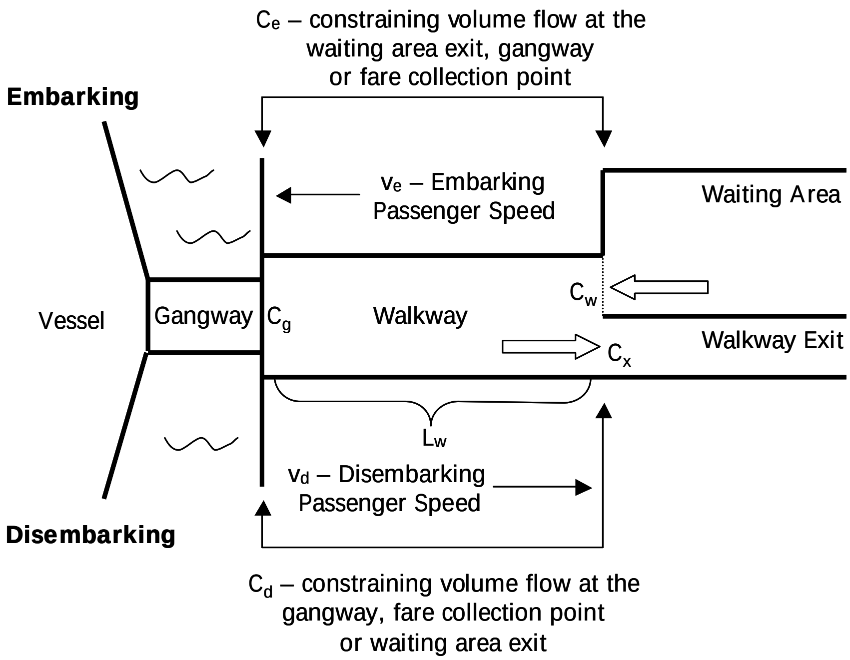
where:

t_{ed} = total embarking and disembarking time (s/vessel);
60 = number of seconds in 1 minute;
C_d = disembarking capacity at the constraining point (p/min);
C_e = embarking capacity at the constraining point (p/min);
P_d = disembarking passenger volume (p);
P_e = embarking passenger volume (p);
L_w = walkway length (ft, m);
v_d = disembarking passenger speed on walkway, from Exhibit 7-1 (U.S. customary units) or Exhibit 7-1m (metric units) (ft/min, m/min);
v_e = embarking passenger speed on walkway (ft/min, m/min);

For relatively uncongested situations (i.e., walkway LOS "C" or better), 250 ft/min (75 m/min) is a reasonable default passenger speed.

These parameters are illustrated in Exhibit 6-13.

Exhibit 6-13
Embarking and Disembarking Parameters



Note: The gangway is considered as a point and hence the time to traverse its length is not included.

Passenger speeds on the walkway can be determined using Exhibits 7-1 and 7-2, starting with a known capacity of the gangway or waiting area exit that constrains how quickly passengers can enter the walkway. For example, if the walkway is 6 feet (1.8 meters) wide and the gangway can process 60 passengers per minute, the pedestrian flow per unit width entering the walkway from the gangway is 10 pedestrians per minute per foot width (33 pedestrians per minute per meter width). Using the right (uncongested) side of the uni-directional commuter curve in Exhibit 7-2 gives a pedestrian space of approximately 26 square feet (2.5 square meters) per passenger at this pedestrian flow per unit width. Applying this result to Exhibit 7-1 gives an average pedestrian walking speed of 250 ft/min (75 m/min).

The disembarking capacity, C_d, will be constrained by the gangway capacity, fare collection time exiting the vessel (if applicable), or the capacity of the walkway exit leading to the terminal building or the shore, as shown in Equation 6-4:

Equation 6-4

$$C_d = \min\begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_x N_{ce} \end{Bmatrix}$$

where:

C_g = gangway capacity (p/min/channel);
N_{cg} = number of gangway channels (i.e., the number of people who can simultaneously exit the vessel);
60 = number of seconds in 1 minute;
N_f = number of fare collectors;
C_x = capacity of the walkway exit (p/min/channel);
N_{ce} = number of channels at the walkway exit; and
t_f = fare collection time (s/p).

The embarking capacity, C_e, will be constrained by the capacity of the exit from the passenger waiting area, fare collection time boarding the vessel or at the waiting room exit (if applicable), or the gangway capacity, as shown in Equation 6-5:

Equation 6-5

$$C_e = \min \begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_w N_{cw} \end{Bmatrix}$$

where:

C_w = capacity of the waiting area exit (p/min/channel); and
N_{cw} = number of channels exiting the waiting area (i.e., the number of people who can simultaneously exit the waiting area).

Gangways can be treated as a free-entry fare gate, and their capacities can be determined from Exhibit 7-20. The capacities of other potential constraining points, such as doors or gates, can also be determined from this exhibit.

When local data on fare collection times are not available, fare collection service times can be approximated using the values for buses given in Exhibits 4-2 and 4-3.

Simultaneous Passenger Embarking and Disembarking

In the event that passenger embarking and disembarking occurs at the same time, inputs to Equation 6-3 should only include the greater of the embarking or disembarking service time. This value is not necessarily dependent upon the magnitude of the embarking or disembarking volume. Although the disembarking volume may be greater than the embarking volume, the service time for embarking passengers may be larger if passengers pay fares when boarding.

Sequential Automobile Disembarking and Embarking

When automobiles and other vehicles are carried, the time required to load and unload these vehicles will usually control the total embarking and disembarking time. This service time is constrained by the time to serve individual vehicles at the gangway, the number of gangway channels available, and the distance between the gangway and the front of the vehicle staging area, as shown in Equation 6-6:

Equation 6-6

$$t_{ed} = \frac{h_v (A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v}$$

where:

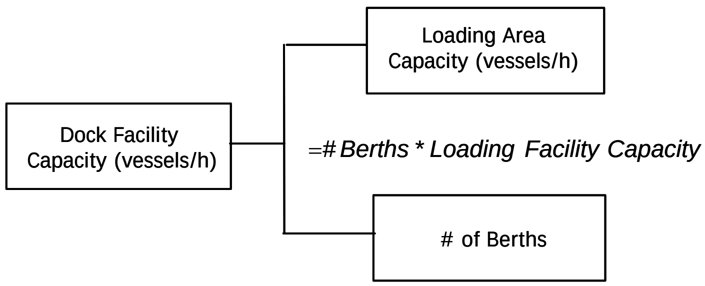
h_v = vehicle headways (s/auto);
A_d = number of disembarking autos (auto equivalent units);
A_e = number of embarking autos (auto equivalent units);
N_{ca} = number of channels for automobiles;
L_r = distance between gangway and front of vehicle staging area (ft, m); and
v_v = vehicle entering/exiting speed (ft/s, m/s).

There are currently no default values for headway or vehicle speed; however, these can be determined from field observations.

Dock Capacity

The vessel capacity of the dock will affect the total number of vessels that can be served at the dock facility per hour. Exhibit 6-14 illustrates the dock facility capacity relationships.

Exhibit 6-14
Dock Capacity Factors



The vessel capacity of a loading area is given by Equation 6-7:

Equation 6-7

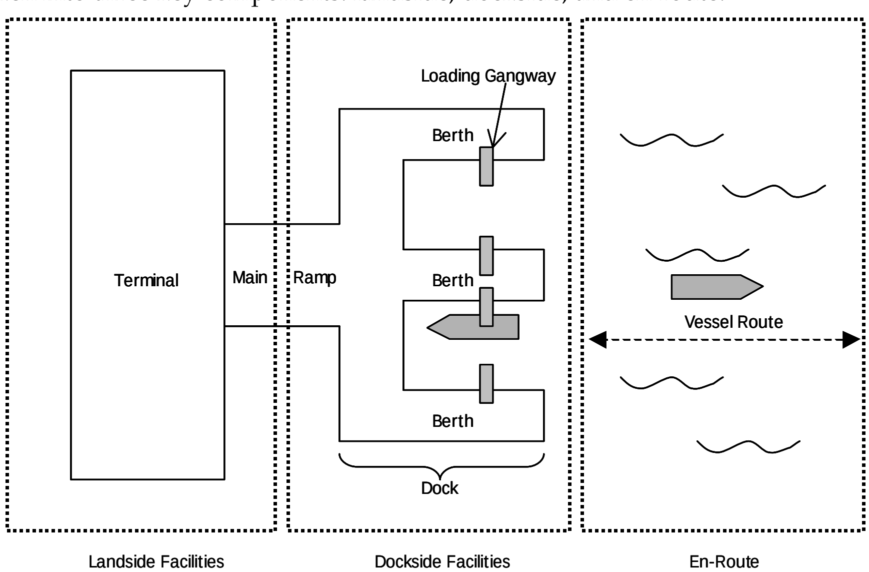
$$V = \sum_{i=1}^{N_b} V_{bi}$$

where:
V = dock vessel capacity (vessels/h);
V_{bi} = vessel capacity of berth i (vessels/h); and
N_b = number of berths at the dock.

PASSENGER AND AUTO CAPACITY

The passenger capacity can be calculated at a number of locations along the passenger's path of travel. These locations are illustrated in Exhibit 6-15 and are broken into three key components: landside, dockside, and en-route.

Exhibit 6-15
Passenger or Auto Flow Through the Ferry Transit System



Landside: The terminal capacity is described in detail in Part 7.

Dockside: The dockside facilities relate to the passenger (auto) capacity of the berth (a single loading area) or the dock (multiple loading areas). As discussed previously, ferry operators can determine how the current or planned demand compares with the vessel capacity of the loading facilities. In a similar manner, it would be useful to compare the current or planned passenger (auto) demand with the passenger (auto) capacity of the loading facilities.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will depend upon the number of vessels serving that berth during the hour. The greater the number of vessels, the greater the total clearance time and, hence, the less time available to load and unload passengers or vehicles. If the embarking and disembarking time for all vessels at the berth exceeds the available time within the hour, then it can be concluded that the passenger (auto) demand exceeds the passenger (auto) capacity of the loading area.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will also depend upon the distribution of embarking and disembarking at a berth for each vessel. When all passengers (autos) disembark all vessels that arrive at the berth, the embarking demand per vessel cannot exceed the vessel's passenger (auto) capacity. When vessels make multiple stops, a portion of the passengers aboard will not disembark. The difference between the vessel's passenger capacity and the number of passengers remaining aboard at a stop represents the embarking passenger capacity for each vessel.

En-Route: The en-route capacity of a ferry system is much less complicated. The capacity or the maximum number of passengers (autos) on a given route is generally based on operator policy, which includes the vessel headway and the vessels' passenger and automobile capacity. The passenger capacity is defined as the number of passengers per hour that can be accommodated based on the current headway and vessel passenger capacity.

Equation 6-8

$$P = V_c f (PHF)$$

where:

P	=	person (auto) capacity on the route's maximum load segment (p/h, autos/h);
V_c	=	passenger (auto) capacity of the vessel (p/vessel, autos/vessel);
f	=	vessel frequency (vessels/h); and
PHF	=	peak hour factor.

Licensing issues related to crew size and composition may constrain a vessel's passenger capacity.

Unlike other modes, where passenger capacity is related only to seating and standing area available, the passenger capacity on the vessel is also affected by policy and licensing issues. Some vessels may have three or four different licenses, whereby the passenger limit will depend upon the size and composition of the crew. Ferry operators may need to match the crew size and passenger license to projected passenger demand. For autos, the concept of AEUs, described earlier in this chapter, is used to measure vehicle capacity on the vessel. This is a method that weights different vehicle categories based on the space they occupy relative to an automobile.

A "peak hour factor" is used in the bus and rail sections of the TCQSM to account for the peak 15 minutes of the peak hourly demand. This ensures that the peak-within-the-peak hourly flow can be accommodated. With a few exceptions (such as Vancouver's SeaBus and New York's Staten Island Ferry), most North American passenger ferry operations are operated at headways of 30 minutes or longer. In this respect, ferry service is similar to many commuter rail operations. A peak hour factor of 0.90 to 0.95 is recommended to allow for variations in demand and to ensure that all passengers who wish to board a given trip are able to do so. Auto ferries that require advance reservations can use a PHF of 1.00, as all available vehicle space will be utilized whenever possible, and there is no passenger expectation of space being guaranteed on the next departing ferry.

CHAPTER 2. REFERENCES

1. Ad Hoc Ferry Transit Environmental Impact Panel, *Ferry Transit for the Twenty-First Century,* Society of Naval Architects and Marine Engineers (January 2000).
2. Bay Area Council, *Bay Area Water Transit Initiative* (1999). http://www.bayareacouncil.org/watertransit/bawt_actionplan.html.
3. Neill, S.M., *A Survey of Waterway Capacity and Policy Issues,* Marine Board Seminar on Waterways and Harbor Capacity (April 2001).
4. Volpe National Transportation Systems Center, *Access for Persons with Disabilities to Passenger Vessels and Shore Facilities,* Final Report, U.S. Department of Transportation, Washington, DC (July 1996). http://ntl.bts.gov/DOCS/rptfinal/rptfinal1.html.

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CHAPTER 3. EXAMPLE PROBLEMS

Example Problem 1

The Situation

A short passenger ferry route is planned that connects three locations along and across a river. For scheduling purposes, it is desired to know how long vessels will stop at each location.

The Question

What are appropriate vessel service times to plan for at the three stops, during the afternoon peak period?

The Facts

- The route will use a ferry with a 50-person capacity.
- Ticket machines located on the shore will be used to issue tickets; a crewmember will collect the tickets at the gangway.
- The ferry has one doorway and hence there is sequential passenger disembarking and embarking.
- The average number of embarking and disembarking passengers per stop during the afternoon peak period is forecast as follows:

Stop #	1	2	3
Disembarking Passengers	10	20	40
Embarking Passengers	30	10	10

- The docks have a gangway width of 1 meter. Sloped walkways lead from each dock onto the shore. The walkways have dimensions of 2x15 meters and each walkway ends in a pair of free-swinging gates opening outward into an uncovered waiting area. Embarking passengers are not allowed onto the walkway until the disembarking passengers have exited.

Comments

- Based on observations of a ferry operation with similar mooring operations and gangway equipment to that proposed, the clearance time is estimated to be 90 seconds (45 seconds upon arrival and 45 seconds upon departure).
- Because berth capacity is not being calculated, the operating margin component of Equation 6-2 does not need to be used.
- From Exhibit 7-24, average capacities for manual ticket collection are 30 persons per minute (i.e., 2 seconds per person). Both the gangway and the walkway exit gates can be treated as free-admission gates, which have a capacity range of 40-60 persons per minute per channel. The lower value (40 persons per minute per gate) will be assumed for the walkway exit gates, as these require physically pushing or pulling the gates to open them, or to keep them open, while the higher value (60 persons per minute per channel) will be assumed for the gangway, as passengers can pass through it freely. A 1-meter-wide gangway is the equivalent of one channel.

Outline of Solution

All input parameters are known. The vessel service time will be calculated using Equation 6-2, without the operating margin component. As passenger movement along the walkway occurs in one direction at a time, embarking and disembarking times will need to be calculated separately for each stop to determine their contribution to vessel service times.

Solution

1. Calculate the disembarking capacity using Equation 6-4. This capacity is constrained by the gangway, fare collection (not applicable for disembarking), or the walkway exit.

$$C_d = \min\begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_x N_{ce} \end{Bmatrix}$$

$$C_d = \min\begin{Bmatrix} 60(1) \\ N/A \\ 40(2) \end{Bmatrix}$$

$$C_d = 60 \text{ p/min}$$

2. Calculate the embarking capacity using Equation 6-5. This capacity is constrained by the gangway, fare collection, or the walkway entrance.

$$C_e = \min\begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_w N_{cw} \end{Bmatrix}$$

$$C_e = \min\begin{Bmatrix} 60(1) \\ 60(1/2.0) \\ 40(2) \end{Bmatrix}$$

$$C_e = 30 \text{ p/min}$$

3. Determine the total embarking and disembarking time from Equation 6-3.

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

$$t_{ed} = 60\left(\frac{10}{60} + \frac{15}{75} + \frac{30}{30} + \frac{15}{75}\right)$$

$$t_{ed} = 94 \text{ s}$$

4. Calculate the vessel service time from Equation 6-2, omitting the operating margin component.

$$t_v = t_{ed} + t_c$$

$$t_v = 94 + 90$$

$$t_v = 184 \text{ s}$$

The Results

Estimated vessel service times for planning purposes are shown below for each stop:

Stop #	1	2	3
Vessel Service Time (s)	184	154	174

Changing the proposed fare collection system to avoid fare collection at the gangway would improve the vessel service time by an average of 30 seconds per stop. Improvements in the gangway or mooring technology could also be considered to improve service times, as the planned 90 seconds forms a significant portion of the total time.

Example Problem 2

The Situation

An new auto ferry route is planned to connect two locations on opposite sides of a bay. It is desired to know how long a typical ferry on this route will occupy the berth when auto demand equals or exceeds the ferry's capacity.

The Question

What is the average vessel service time when the ferry is fully loaded entering and leaving the dock?

The Facts

- The route will use a ferry with a capacity of 100 autos.
- The fare will be collected in the auto staging area prior to embarking.
- The ferry will have sequential auto disembarking and embarking.
- The gangway can accommodate two lanes of vehicles and is located 50 meters from the front of the vehicle staging area.

Comments and Assumptions

- The clearance time, based an investigation of similar mooring and gangway technology, is estimated to be 3 minutes (1.5 minutes upon arrival and 1.5 minutes upon departure).
- Because berth capacity is not being calculated, the operating margin component of Equation 6-2 does not need to be used.
- Assume that the vehicle headway is 3.0 s/auto.
- Assume that the approximate auto entry speed is 15 km/h (4.2 m/s).

Outline of Solution

The vessel service time for autos can be approximated using Equation 6-2, omitting the operating margin component of the equation. As a result, the service time calculation includes the time associated with auto embarking and disembarking, and the clearance time.

Steps

1. Determine the total embarking and disembarking time from Equation 6-3.

$$t_{ed} = \frac{h_v(A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v}$$

$$t_{ed} = \frac{3(100+100)}{2} + \frac{2(50)}{4.2}$$

$$t_{ed} = 324\text{ s}$$

2. Calculate the vessel service time from Equation 6-2, omitting the operating margin component.

$$t_v = t_{ed} + t_c$$

$$t_v = 324 + 180$$

$$t_v = 504\text{ s}\ \ (8\text{ minutes, }24\text{ seconds})$$

Example Problem 3

The Situation

A passenger ferry berth currently serves six ferries during the evening peak hour. The transit agency wishes to add another ferry during the peak hour.

The Question

Are additional berths required?

The Facts

- The observed average passenger embarking and disembarking time at the berth is 3 minutes.
- The observed clearance time is a total of 4 minutes (2 minutes upon arrival and 2 minutes upon departure).

Comments and Assumptions

- Observations indicate that c_V (the coefficient of variation in the embarking/ disembarking time) is 0.60.
- The design failure rate is 10%, which corresponds to a *Z* factor of 1.280 (see Exhibit 4-6).

Outline of Solution

All input parameters are known. The number of vessels per hour that can be accommodated by a single berth can be determined using Equation 6-2.

Steps

1. Calculate the vessel service time, Equation 6-2.

$$t_v = t_{ed} + Zc_v t_{ed} + t_c$$
$$t_v = 180 + (1.280)(0.6)(180) + 240$$
$$t_v = 558 \text{ s}$$

2. Determine the maximum number of vessels per hour that the berth can accommodate based on the demand, Equation 6-1.

$$V_b = \frac{3600}{t_v}$$
$$V_b = \frac{3600}{558}$$
$$V_b = 7 \text{ vessels/h}$$

The Results

One berth is sufficient to serve the six existing plus one planned ferry at the dock.

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