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Highlights of the Transit Capacity and Quality of Service Manual: First Edition

This TCRP digest contains edited excerpts from the Transit Capacity and Quality of Service Manual: First Edition, *which is available on the world wide web as* TCRP Web Document 6 *at this address:* http://www4.nas.edu/trb/crp.nsf. *It is also available from TCRP on CD-ROM This digest presents the basic capacity concepts and introduces a systematic approach to measuring the quality of transit service from a passenger's point of view The work was performed by a team led by Kittelson & Associates, Inc, for TCRP Project A-15. For detailed procedures, refer to* TCRP Web Document 6.

BACKGROUND

This digest and its companion, *TCRP Web Document 6,* will be of interest to anyone who designs or sponsors transit services. It contains the basic capacity and quality of service concepts for bus service, paratransit services, light rail service, and heavy rail service. It is intended to familiarize practitioners with these concepts and encourage the use of the detailed analytical procedures contained in *TCRP Web Document 6, Transit Capacity and Quality of Service Manual: First Edition* (TCQSM).

Until the publication of the TCQSM, the transportation profession lacked a consolidated set of transit capacity and quality of service definitions, principles, practices, and procedures for planning, designing, and operating vehicles and facilities. This is in contrast to the *Highway Capacity Manual* (HCM) that defines quality of service and presents fundamental information and computational techniques related to quality of service and capacity of highway facilities. The HCM also provides a focal point and structure for advancing the state of knowledge. It is anticipated that the TCQSM will provide similar benefits.

The First Edition of the TCQSM is a start toward providing the transportation industry with a transit companion to the HCM. "Transit capacity" deals with the movement of people and vehicles, depends on the size of the transit vehicles and how often they operate, and reflects the interaction between passenger traffic and vehicle flow. "Quality of service" is an even more complex concept that must reflect a transit-user's perspective and must measure how a transit route, facility, or system is operating under various demand, supply, and control conditions.

TCRP Project A-15 was a start toward addressing these issues. The objectives of TCRP Project A-15 were to (1) define the content of a comprehensive Transit Capacity and Quality of Service Manual, (2) provide transit input to the *Highway Capacity Manual 2000,* (3) develop a prioritized research agenda for completing the Transit Capacity and Quality of Service Manual, (4) complete those portions of a Transit Capacity and Quality of Service Manual for which information is available and produce a first edition document, and (5) conduct research on one or more high-priority research topics growing out of the research agenda. These objectives were accomplished by the project, which produced a first edition TCQSM. In the first phase of TCRP Project A-15, the research team performed market research on what potential users would like to see in a TCQSM, assembled and edited existing information on transit capacity, and conducted original research on measuring transit quality of service.

The TCQSM is organized into six parts:

- Part 1: Introduction and Concepts
- Part 2: Bus Transit Capacity
- Part 3. Rail Transit Capacity
- Part 4: Terminal Capacity
- Part 5: Quality of Service
- Part 6: Glossary

CONTENTS

Each of the first five parts is organized into chapters, the contents of which are described in the corresponding sections of this digest. References are not included in the digest, but are listed by chapter in *TCRP Web Document 6.*

Comments on the first edition are welcome. A process is being established to respond to user comments, and a research agency has been engaged to prepare a second edition. The Transportation Research Board has also established a Task Force on Transit Capacity and Quality of Service (A1E53) that will oversee the long-term evolution of the TCQSM. Written comments may be sent to TCRP at this address: Transit Cooperative Research Program, 2101 Constitution Avenue, NW, Washington, D.C. 20418. Refer to the TCRP website for updates on how to submit comments. Select "TCRP, All Projects, A-15" at this address: http:// www4.nas.edu/trb/crp.nsf.

SECTION 1

TRANSIT CAPACITY AND QUALITY OF SERVICE CONCEPTS

INTRODUCTION

Transit capacity differs from highway capacity in that it deals with the movement of *both* people and vehicles, depends on the size of the transit vehicles and how often they operate, and reflects the interaction between passenger traffic concentrations and vehicle flow. Transit capacity also depends on the operating policy of the transit agency, which normally specifies service frequencies and allowable passenger loadings. Accordingly, the traditional concepts applied to highway capacity must be adapted and broadened.

Although transit capacity issues are mainly concentrated in larger cities, transit quality of service--the overall measured or perceived performance of transit service from the passenger's point of view--is important to all communities. Transit quality of service measures reflect two important aspects of transit service: (1) the degree to which transit service is *available* to given locations and (2) the comfort and convenience, or *quality,* of the service provided to passengers. Quality of service measures differ from both traditional highway service quality measures, which are more vehicle-oriented than person-oriented, and the numerous utilization and economic performance measures routinely collected by the transit industry, which tend to reflect the transit operator's point-of-view.

CAPACITY

At the simplest level, transit capacity is determined by the product of transit vehicle capacity and the maximum frequency with which transit vehicles can pass a given location. The person capacity or passenger-carrying capability for any given transit route can be defined as the maximum number *of people* that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty. More specifically, person capacity depends on the mix of vehicles in the traffic stream, including the number and occupancy of each type of vehicle that can reasonably be expected to pass a point on a transit route. Person capacity is a function of vehicle size, type, occupancy, and headway. The number of transit vehicles along a route reflects the degree of scheduled service.

The passenger capacity of a transit line is the product of the number of vehicles per hour (usually past the busiest stop) and the number of passengers that each vehicle can carry. Four basic factors determine the maximum passenger capacity:

1. The maximum number of vehicles per transit unit (e.g., bus, car, or train);
2. The passenger capacity of the individual transit vehicles;
3. The minimum possible headway or time spacing between individual vehicles or trains; and
4. The number of lanes or passenger-loading positions available.

The factors that influence transit capacity are given in Table 1. Some of these factors affect the number of passengers per unit, while others affect the number of units that can pass a given location within a specified period. The range of achievable capacities for various transit modes and the highest observed North American values are shown in Figure 1.

The capacity of a transit line varies along the route. Limitations may occur between stops (i.e., way capacity), at stops or stations (i.e., station capacity), at major intersections with cross traffic, or at terminals (station capacity).

Transit line capacity is generally governed by the critical stops where major passenger boarding or alighting occurs or where vehicle routes terminate or turn around. This is similar to estimating arterial street capacity on the basis of critical intersections along a route. Sometimes, however, outlying rail transit terminals limit system capacity because of heavy passenger boardings and track configurations or operating practices that limit train turnarounds.

In many cases, the design capacity of a transit route will not be achieved in actual operation. Frequently, this is a result of resource limitations whereby not enough transit vehicles are available to provide the maximum possible design capacity. In many cases, passenger demand may not be sufficient to justify operation at the design capacity. The net result either way is that service frequency is below that which is theoretically possible.
The following considerations are important:

1. The *maximum* rate of passenger flow is usually constrained by factors such as acceptable levels of passenger

TABLE 1 Factors that influence transit capacity

1.	*Vehicle Characteristics*
•	Allowable number of vehicles per transit unit (i.e., single unit or bus or several units or cars per train)
•	Vehicle dimensions
•	Seating configuration and capacity
•	Number, location, and width of doors
•	Number and height of steps
•	Maximum speed
•	Acceleration and deceleration rates
•	Type of door actuation control
2.	*Right-of-Way Characteristics*
•	Cross-section design (i.e., number of lanes or tracks)
•	Degree of separation from other traffic
•	Intersection design (i.e., at-grade or grade-separated type of traffic controls)
•	Horizontal and vertical alignment
3.	*Stop Characteristics*
•	Spacing (frequency) and duration
•	Design (online or offline)
•	Platform height (high-level or low-level loading)
•	Number and length of loading positions
•	Method of fare collection (e.g., prepayment, pay when entering vehicle, or pay when leaving vehicle)
•	Type of fare (e.g., single-coin, penny, or exact)
•	Common or separate areas for passenger boarding and alighting
•	Passenger accessibility to stops
4.	*Operating Characteristics*
•	Intercity versus suburban operations at terminals
•	Layover and schedule adjustment practices
•	Time losses to obtain clock headways or provide driver relief
•	Regularity of arrivals at a given stop
5.	*Passenger Traffic Characteristics*
•	Passenger concentrations and distribution at major stops
•	Peaking of ridership (i.e., peak-hour factor)
6.	*Street Traffic Characteristics*
•	Volume and nature of other traffic (in shared right-of-way)
•	Cross traffic at intersections if at-grade
7.	*Method of Headway Control*
•	Automatic or by driver/train operator
•	Policy spacing between vehicles

comfort, the presence of other traffic sharing the same right-of-way, and safety considerations. Therefore, transit operators generally are more concerned with the realistic rates of flow that can be achieved by different modes, rather than with physical capacity in the theoretical sense.

2. Operations at "capacity" tend to strain transit systems and do not represent desirable operating conditions. Moreover, most North American transit systems operate at capacity for a relatively short period of time, if at all.
3. Capacity relates closely to system performance and service quality in terms of speed, comfort, and service reliability. A single, fixed number often can be misleading.

   The concept of "productive capacity," the product of passenger flow and speed, provides an important index of system efficiency.
4. Capacities obtained by analytical methods must be cross-checked against actual operating experience for reasonableness.

Loading Diversity

The temporal and spatial distribution of transit passengers often prevents transit capacity from being fully achieved during the peak period. In the temporal sense, peaks within the peak period occur at major work start and finish times and can result in brief periods of operation at capacity followed by under-capacity operation. Short-term fluctuations in ridership demand must be considered to avoid unacceptable passenger queuing or overcrowding. Variations in arrival patterns and dwell times at stops will tend to reduce capacity. Temporal diversity can be accommodated in capacity calculations through the use of a peak hour factor, as will be described later.

Spatial diversity can be manifested in numerous ways--from boarding and alighting locations at the macro scale to the distribution of passengers within the vehicle at the micro scale. A transit line with a relatively uniform distribution of boarding passengers among stops will usually have a higher capacity than one where passenger boarding is concentrated at a single stop. Loading is often uneven between cars in a single train or between buses operating together on a single route.

Economic Constraints

Economic factors often constrain capacity at a level below that is technically feasible and suggested by passenger demand. For example, a shortage of vehicles to supply service on a given route may result in passengers being left behind and crowding conditions that deter would-be riders. A survey of rail transit systems found that the passing up of waiting passengers was relatively rare except on some subway lines in New York City and Toronto and occasionally on the SkyTrain in Vancouver. However, in the New York and Toronto cases, trains were being operated at close to the minimum headway so the constraint was not so much economic, barring the construction of new subway lines or extending platforms, but technical. In the Vancouver case, passengers would voluntarily wait for a less crowded train, indicating that crowding conditions were at least partially avoidable. Systems in other cities, such as Portland, Oregon, indicated that their available capacity was constrained by a shortage of cars and that this capacity shortfall was discouraging new ridership on the light rail line.

Agency Policies

Transit agency policies can influence capacity levels by dictating policy headways and vehicle-loading standards. Policies are often set to ensure that scheduled service operates below capacity in order to provide a higher degree of passenger comfort. This can be manifested in the form of more frequent service or the use of larger vehicles than would be the case with lighter loading standards. Such policies can be the result of safety decisions, such as the banning of standees on buses operating on freeways, or a desire to ensure that the transit system remains attractive to new riders.

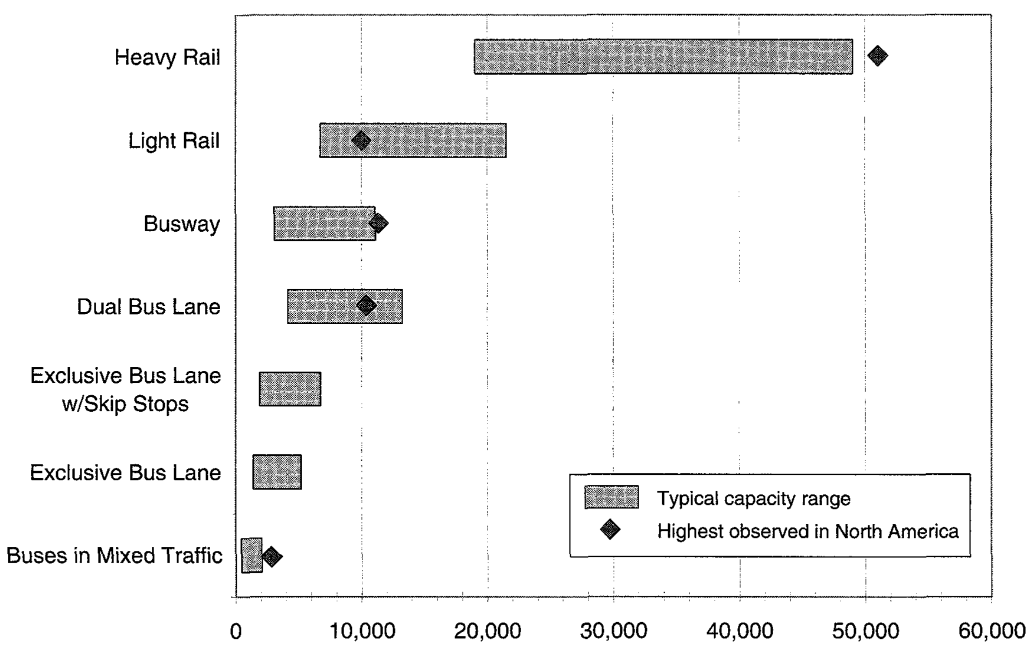

Figure 1. Achievable capacity (peak direction passengers/hour).

The latter justification is especially important where transit is unable to provide a large travel-time saving to the commuter and so must compete more directly with the automobile in comfort and convenience.

QUALITY OF SERVICE

Quality of service reflects the kinds of decisions a potential passenger makes, consciously or not, when deciding whether to use transit or another mode (usually the private automobile). There are two parts to this decision process: (1) assessing whether transit is even an option for the trip, and if so, (2) comparing the comfort and convenience of transit with competing modes.

Transit Availability

Unlike the automobile mode, which has near-universal access to locations and (for those who own an automobile) can be used for trips at any time, transit service is limited to specific areas and specific times. Further, transit service is usually not available to one's door, so a potential transit passenger must find a way to get to a location served by transit. As a result, the availability of transit service is critical to one's decision to use transit.

Several conditions affect transit availability--all of which must be met for transit to be an option for a particular trip:

- *Transit must be provided near one's trip origin.* If demand-responsive service is not provided to one's door, a transit stop must be within walking distance and the pedestrian environment in the area should not discourage walking (e.g., because of lack of sidewalks, steep grades, or wide or busy streets). Alternatively, one may be able to ride a bicycle to a transit stop if bicycle storage facilities are available at the stop or if bicycles can be carried on transit vehicles. One may also be able to drive to a park-and-ride facility if one is provided along the way and space is available in the parking lot.
- *Transit must be provided near one's destination.* The same kinds of factors discussed for the trip origin apply to the trip destination as well, except that bicycles or automobiles left behind at the boarding transit stop will not be available to passengers at their destination.
- *Transit must be provided at or near the times required.* In most cases, service must be available for both halves of a round trip--from one's origin to one's destination, as well as for the return trip. If a passenger perceives a risk of missing the final return trip of the day or if transit is available for only one of the two halves of the passenger's round trip, transit is not likely to be an option for this passenger.
- *Passengers must be able to find information on when and where transit service is provided and how to use transit.* If passengers cannot find out where to go to board transit, where to transfer, and so forth, transit will not be an option.
- *Sufficient capacity must be provided.* If a transit vehicle must pass up passengers waiting at a stop, transit service was not available to those waiting passengers at that time.

If all of these conditions are met, transit is an *option* for a particular trip. Whether or not a passenger will decide to use transit will depend on the *quality* of the service relative to competing modes.

Transit Quality

Unlike transit availability, the kinds of questions weighed by potential passengers when assessing the comfort and convenience of transit service are not necessarily all or nothing. Each person assesses the factors that enter into transit quality differently, depending on his or her needs and situation. A passenger's decision to use transit rather than a competing mode (when transit is an option) will depend on how well transit service quality compares with that of competing modes.

Some of the more important factors that affect transit quality are as follows:

- *Passenger loads* on board transit vehicles (e.g., it is more uncomfortable to stand for long periods, and the time spent standing cannot be used for more productive or relaxing purposes, such as reading); The kinds of *passenger amenities* provided at transit stops;
- The *reliability* of transit service (e.g., are passengers assured of getting to their destinations at the promised time or must they allow extra time for frequent schedule irregularities?);
- *Door-to-door travel times,* relative to other modes;
- The out-of-pocket *cost* of using transit, relative to other modes;
- Passengers' perceptions of *safety and security* at transit stops, on board vehicles, and walking to and from transit stops;
- Whether *transfers* are required to complete a trip; and
- The *appearance and comfort* of transit facilities.

Quality of Service Framework

The TCQSM: First Edition, presents six measures of transit quality of service: three measures of the spatial and temporal availability of transit and three measures of passenger comfort and convenience. Depending on the application, these service measures can be used individually to assess transit quality of service for a transit stop, route segment, or system, or they can be combined into a transit "report card" to provide a broader perspective. As not every factor that affects transit quality of service can be accounted for by these six service measures, planners and analysts must not lose sight of the broader issues that influence transit quality of service by concentrating solely on calculations of level of service. To be competitive, transit travel times must be reasonable and reliable.

SECTION 2

BUS TRANSIT CAPACITY BASICS

INTRODUCTION

Bus capacity deals with the movement of both people and vehicles, depends on the size of the buses used and how often they operate, and reflects the interaction between passenger traffic concentrations and vehicle flow. It also depends on the operating policy of the service provider, which normally specifies service frequencies and allowable passenger loadings. Ultimately, the capacities of bus routes, bus lanes, and bus terminals, in terms of persons carried, are generally limited by (1) the ability of stops or loading areas to accommodate the pick up and discharge of passengers, (2) the number of vehicles operated, and (3) the distribution of boardings and alightings along a route.

Part 2 of the TCQSM presents methods for calculating bus capacity and speed for various facility and operating types. The chapters and appendixes are as follows:

- Chapter 1 introduces the basic factors and concepts that determine bus capacity.
- Chapter 2 discusses bus and roadway operating issues that influence bus capacity.
- Chapters 3 through 6 present capacity and speed calculation procedures for four facility and operating categories.
- Chapter 7 contains references for material presented in Part 2 of the TCQSM. This may be consulted for further information on how the procedures were developed.
- Chapter 8 presents example problems that illustrate how to apply the procedures introduced in Part 2 to realworld situations.
- Appendix A provides a procedure for collecting bus dwell time data in the field.
- Appendix B provides substitute exhibits in U.S. customary units for Part 2 exhibits that use metric units.

DEFINITIONS

A distinction is made between *vehicle* and *person* capacity. Vehicle capacity reflects the number of buses that can be served by a loading area, bus stop, bus lane, or bus
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route during a specified period. Person capacity reflects the number of people that can be carried past a given location during a given time under specified operating conditions without unreasonable delay, hazard, or restriction and with reasonable certainty.

This definition of person capacity is less absolute than the definition of vehicle capacity, because person capacity depends on the allowable passenger loading set by operator policy and the number of buses operated. Because the time that passengers remain on a bus affects the total number of passengers that may be carried over the entire length of a route, person capacity is often measured at a route's maximum load point. For example, an express bus may have most of its passengers board in a suburb and disembark in the central business district. In this situation, the number of passengers carried at the maximum load point will be close to the total number of boarding passengers. For a local bus, with various potential passenger trip generators along the length of the route, the number of persons carried over the length of the route will be significantly greater than the express bus, although both bus' passenger loads at their respective maximum load points may be quite similar.

TYPES OF BUS FACILITIES AND SERVICE

The capacity procedures presented in Part 2 of the TCQSM categorize bus service by the kinds of facilities that buses operate on, and, in the case of demand-responsive service, by the special operating characteristics that influence capacity. These procedures will be presented in order from the most exclusive kinds of facilities used by buses to the least exclusive.

The most exclusive facilities, and often the facilities where buses can achieve the highest speeds, are *busways* and *freeway high-occupancy vehicle (HOV) lanes.* Busways are special roadways designed for exclusive use by buses. A busway may be constructed at, above, or below grade and may be either within a separate right-of-way or within a highway corridor. Buses share freeway HOV lanes with carpools and vanpools, but avoid the congestion in the regular freeway lanes.

Another form of bus facility is the *exclusive arterial street bus lane,* typically found along downtown streets. These lanes are reserved primarily for buses, either all day or during specified periods. Depending on local regulations, they may be used by other traffic under certain circumstances, such as by vehicles making turns, or by taxis, motorcycles, carpools, or other vehicles that meet certain requirements.

The most common operating environment for buses is in *mixed traffic,* where buses share roadways with other traffic. In this environment, capacity procedures must account for the interactions between buses and other traffic and whether or not buses stop in the traffic lanes *(online stops)* or out of the traffic lanes *(offline stops)*

The final category of bus service is *demand-responsive service.* Unlike the other categories, which address the capacity of facilities, demand-responsive capacity depends mostly on operating factors, including the number of vehicles available, the size of the service area, and the amount of time during which service is offered.

FACTORS INFLUENCING BUS CAPACITY

This section presents the primary factors that determine bus vehicle and person capacity. Although many of the individual factors influencing vehicle capacity differ from those influencing person capacity, this section will show that there are strong connections between vehicle and person capacity, as well as between capacity in general and the concept of quality of service introduced in Part 5.

Vehicle Capacity

Vehicle capacity is commonly calculated for three locations:

- Loading areas (bus berths),
- Bus stops, and
- Bus lanes.

Each of these locations has one or more elements that determine its capacity, and each of these elements has factors that further influence capacity. Figure 2 shows bus vehicle capacity factors.

Loading Areas

A loading area, or bus berth, is a space for buses to stop and board and discharge passengers. Bus stops, discussed below, contain one or more loading areas.

The most common form of loading area is a linear bus stop along a street curb. In this case, loading areas can be provided in the travel lane *(online),* where following buses may not pass the stopped bus, or out of the travel lane *(offline),* where following buses may pass stopped buses.

The main elements affecting loading area vehicle capacity are as follows:

- *Dwell Time.* Dwell time, the single most important factor affecting vehicle capacity, is the time required to serve passengers at the busiest door, plus the time required to open and close the doors.
- *Dwell Time Variability.* The variations in dwell time among different buses using the same loading area

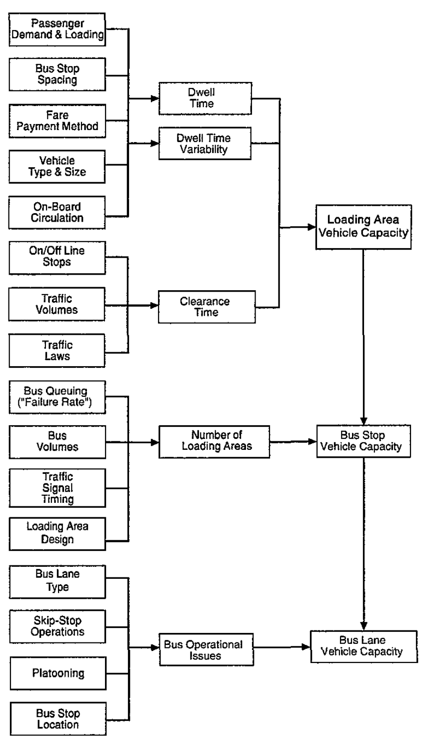

Figure 2. Bus vehicle capacity factors.

affect capacity. The greater the variation, the lower the vehicle capacity.

- *Clearance Time.* Clearance time is the average time between one bus leaving a stop and a following bus being able to enter the stop.

Each of these elements is addressed in more detail below.

Dwell Time. Just as dwell times are key to determining vehicle capacity, passenger demand volumes and passenger service times are key to determining dwell time. Dwell times may be governed by boarding demand (e.g., in the p.m. peak period when relatively empty buses arrive at a heavily used stop), by alighting demand (e.g., in the a.m. peak period at the same location), or by total interchanging passenger demand (e.g., at a major transfer point on the system). In all cases, dwell time is proportional to the boarding and/or alighting volumes multiplied by the service time per passenger. Dwell time can also influence a bus operator's bottom line: if average bus speeds can be increased by reducing dwell time, fewer vehicles may be required to provide the same service frequency on a route, if the cumulative change in dwell time exceeds the existing route headway.

As shown in Figure 2, five main factors influence dwell time:

- *Passenger Demand and Loading.* The number of people boarding and/or alighting through the *highest volume* door is the key factor in how long it will take for all passengers to be served. If standees are present on board a bus as it arrives at a stop, or if all seats become filled as passengers board, service times will be higher than normal because of congestion in the aisle. The mix of alighting and boarding passengers at a stop also influences how long it takes all passenger movements to occur. In certain locations, dwell time can also be affected by the time to board and disembark passengers in wheelchairs and for bicyclists to load bicycles onto or unload bicycles from a bus-mounted bicycle rack.
- *Bus Stop Spacing.* The fewer the stops, the greater the number of passengers who will need to board at a given stop. A balance is required between too few stops (which increase the distance riders must walk to access transit and increase the amount of time an individual bus occupies a stop) and too many stops (which reduce overall travel speeds because of the time lost in accelerating, decelerating, and possibly waiting for a traffic signal every time a stop is made).
- *Fare Payment Method.* The time passengers must spend paying fares is a major factor in the total time required per boarding passenger. This time can be reduced by minimizing the number of bills and coins required to pay a fare; encouraging the use of pre-paid tickets, tokens, passes, or smart cards; using a proof-of-payment fare-collection system; or developing an enclosed, monitored paid-fare area at high-volume stops. In addition to eliminating the time required for each passenger to pay a fare on board the bus, proof-of-payment fare collection systems also allow boarding passenger demand to be more evenly distributed between doors, rather than being concentrated at the front door.
- *Vehicle Type and Size.* Low-floor buses decrease passenger service time by eliminating the need to ascend and descend steps. This is particularly true when a route is frequently used by persons who are elderly, have disabilities, or have strollers or bulky carry-on items.
- *On-Board Circulation.* Encouraging people to exit via the rear door(s) on buses having more than one door decreases passenger congestion at the front door and reduces passenger service times.

Combinations of these five factors can substantially reduce dwell times. Denver's 16th Street Mall shuttle operation can maintain 75-sec peak headways with scheduled 12.5-sec dwell times, despite high peak passenger loads on its 70-passenger buses. This is accomplished through a combination of fare-free service, few seats (passenger travel distances are short), low-floor buses, and three double-stream doors on the buses.

Dwell Time Variability. Not all buses stop for the same amount of time at a stop, depending on fluctuations in passenger demand between buses and between routes. The effect of variability in bus dwell times on bus capacity is reflected by the coefficient of variation of dwell times, which is the standard deviation of dwell time observations divided by the mean dwell time. Dwell time variability is influenced by the same factors that influence dwell time.

Clearance Time. Once a bus closes its doors and prepares to depart a stop, there is a time, known as the clearance time, during which the loading area is not available for use by the following bus. Part of this time is fixed, consisting of the time for a bus to start up and travel its own length, clearing the stop. For online stops, though, this is the only component of clearance time. For offline stops, however, there is another component to clearance time: the time required for a suitable gap in traffic to allow the bus to re-enter the traffic stream and accelerate. This re-entry delay varies depending on the traffic volume in the travel lane next to the stop and increases as traffic volumes increase. The delay also depends on the platooning effect from upstream traffic signals. Some states have passed laws requiring motorists to yield to buses re-entering a roadway; depending on how well motorists comply with these laws, the re-entry delay can be reduced or even eliminated. Many bus operators avoid using offline stops on busy streets in order to avoid this reentry delay.

Bus Stops

A bus stop is an area where one or more buses load and unload passengers. It consists of one or more loading areas.

Bus stop vehicle capacity is related to the vehicle capacity of the individual loading areas at the stop, the bus stop design, and the number of loading areas provided. Offline bus stops provide greater vehicle capacity than do online stops for a given number of loading areas, but in mixed-traffic situations, bus speeds may be reduced if heavy traffic volumes delay buses exiting a stop. The design of off-street bus terminals and transfer centers entails additional considerations.

Bus Terminals. The design of a bus terminal or "transit center" involves not only estimates of passenger service times of buses that will use the center, but also a clear understanding of how each bus route will operate. Therefore, such factors as schedule recovery times, driver relief times, and layovers to meet scheduled departure times become the key factors in establishing loading area requirements and sizing the facility. In addition, good operating practice suggests that each bus route, or geographically compatible groups of routes, should have a separate loading position to provide clarity for passengers.

Loading area space requirements should recognize the specific type of transit operations, fare collection practices, bus door configurations, passenger arrival patterns, amount of baggage, driver layover-recovery times, terminal design, and loading area configuration. They should reflect both scheduled and actual peak period bus arrivals and departures, because intercity bus services regularly run "extras" during the busiest seasonal travel periods.

Bus route and service patterns also influence loading area requirements. Good operating practice calls for a maximum of two distinct routes (i.e., "services") per loading position. Part 4 of the TCQSM describes sizing bus terminals in greater detail.

On-Street Bus Stops. On-street bus stops are typically located curbside in one of three locations: (1) near-side, where the bus stops immediately prior to an intersection, (2) far-side, where the bus stops immediately after an intersection, and (3) mid-block, where the bus stops in the middle of the block between intersections. Under certain circumstances, such as when buses share a stop with streetcars running in the center of the street, or when exclusive bus lanes are in the center of the street, a bus stop may be on a boarding island within the street rather than curbside. When boarding islands are used, pedestrian safety and the Americans with Disabilities Act of 1990 (ADA) accessibility issues should be carefully considered.

Special bus stops are sometimes located along freeway rights-of-way, usually at interchanges or on parallel frontage roads. These stops are used to reduce travel time for buses by eliminating delays associated with exiting and reentering freeways. Freeway stops should be located away from the main travel lanes and adequate acceleration and deceleration lanes should be provided. To be successful, attractive, well-designed pedestrian access to the stop is essential.

The bus stop location influences vehicle capacity, particularly when passenger vehicles are allowed to make right turns from the curb lane (as is true in most situations, except for certain kinds of exclusive bus lanes). Far-side stops have the least effect on capacity (when buses can use an adjacent lane to avoid right-turn queues), followed by mid-block stops, and near-side stops.

However, vehicle capacity is not the only factor that must be considered when selecting a bus stop location. Potential conflicts with other vehicles operating on the street, transfer opportunities, the distances passengers must walk to and from the bus stop, locations of passenger generators, signal timing, driveway locations, physical obstructions, and the potential for implementing transit-preferential measures must also be considered.

For example, near-side stops are preferable when curb parking is allowed, because there is more space for buses to re-enter the moving traffic lane. They are also desirable at intersections where buses make a right turn and at intersections with one-way streets moving from right to left. Where buses operate in the curb lane and/or right-turning traffic is heavy, far-side stops are preferable. Far-side stops are also used at intersections where buses make left turns and at intersections with one-way streets moving from left to right. Mid-block stops are typically only used at major passenger generators or where insufficient space exists at adjacent intersections.

Table 2 lists the advantages and disadvantages of each kind of bus stop location.

As mentioned previously, the vehicle capacity of a bus stop depends primarily on the following two elements:

1. The vehicle capacity of the individual loading areas that constitute the bus stop, and
2. The number of loading areas provided and their design.

The vehicle capacity of loading areas was discussed in the previous section. The factors that determine how many loading areas need to be provided at a given bus stop, shown in Figure 2, and are examined in more detail below.

Bus Stop Loading Area Requirements. The following key factors influence the number of loading areas required at a bus stop:

- *Bus Volumes.* The number of buses scheduled to use a bus stop during an hour directly affects the number of buses that may need to use the stop at a given time. If insufficient loading areas are available, buses will queue behind the stop, decreasing its vehicle capacity. In this situation, passenger travel times will increase, and the on-time reliability experienced by passengers will decrease, both of which negatively affect quality of service.
- *Probability of Queue Formation.* The probability that queues of buses will form at a bus stop, known as the

TABLE 2 On-street bus stop location comparison

Location	Advantages	Disadvantages
Far-Side	• Minimizes conflicts between right-turning vehicles and buses • Provides additional right-turn capacity by making curb lane available for traffic. • Minimizes sight distance problems on intersection approaches • Encourages pedestrians to cross behind the bus • Creates shorter deceleration distances for buses, since the intersection can be used to decelerate • Buses can take advantage of gaps in traffic flow created at signalized intersections	• May result in intersections being blocked during peak periods by stopped buses • May obscure sight distance for crossing vehicles • May increase sight distance problems for crossing pedestrians • Can cause a bus to stop far side after stopping for a red light, interfering with both bus operations and all other traffic • May increase the number of rear-end crashes since drivers do not expect buses to stop again after stopping at a red light • Could result in traffic queued into intersection when a bus stops in the travel lane
Near-Side	• Minimizes interferences when traffic is heavy on the far side of the intersection • Allows passengers to access buses closest to crosswalk • Intersection width available for bus to pull away from the curb • Eliminates potential for double stopping • Allows passengers to board and alight while bus stopped for red light • Allows driver to look for oncoming traffic, including other buses with potential passengers	• Increases conflicts with right-turning vehicles • May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians • May cause sight distance to be obscured for side street vehicles stopped to the right of the bus • Increases sight distance problems for crossing pedestrians
Mid-Block	• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion	• Requires additional distance for no-parking restrictions • Encourages passengers to cross street mid-block (jaywalking) • Increases walking distance for passengers crossing at intersections

failure rate, is a design factor that should be considered when sizing a bus stop.

- *Loading Area Design.* Loading area designs other than linear (e.g., sawtooth and drive-through) are 100 percent effective: the bus stop vehicle capacity equals the number of loading areas times the vehicle capacity of each loading area, because buses can maneuver in and out of the loading areas independently of other buses. Linear loading areas, on the other hand, have a decreasing effectiveness as the number of loading areas increases, because it is not likely that the loading areas will be equally used. Buses may also be delayed in entering or leaving a linear loading area by buses stopped in adjacent loading areas.
- *Traffic Signal Timing.* The amount of green time provided to a street that buses operate on affects the maximum number of buses that could arrive at a bus stop during an hour.

Bus Lanes

A bus lane is any lane on a roadway in which buses may operate. It may be used exclusively by buses, or it may be shared with other traffic. The vehicle capacity of a bus lane is influenced by the capacity of the critical bus stop located along the lane, which typically is the stop with the highest volume of passenger movements. However, the critical stop might also be a stop with an insufficient number of loading areas. Bus lane capacity is also influenced by the following operational factors:

- *Bus Lane Type.* The vehicle capacity procedures define three bus lane types. Type 1 bus lanes have no use of the adjacent lane; Type 2 bus lanes have partial use of the adjacent lane, which is shared with other traffic; and Type 3 bus lanes provide for exclusive use of two lanes by buses. The curb lane of Type 1 and 2 lanes may or may not be shared with other traffic. The greater the degree of exclusivity of the bus lane and the greater the number of lanes available for buses to maneuver, the greater the bus lane capacity.
- *Skip-Stop Operation.* Bus lane capacity can be increased by spreading out bus stops, so that only a portion of the routes using the bus lane stop at a particular set of stops. (Skip-stop operation is different from limited stop service, where certain buses on a particular route do not stop at selected stops.) This block skipping pattern allows for a faster trip and reduces the number of buses stopping at each bus stop, although it also increases the

complexity of the bus system to new riders and may also increase passenger walking distances to bus stops.

- *Platooning.* When skip stops are used, forming buses into platoons at the start of the skip-stop section maximizes the efficiency of the skip-stop operation. Each platoon is assigned a group of stops in the skip-stop pattern to use. The platooned buses travel as "trains" through the skip-stop section. The number of buses in each platoon ideally should equal the number of loading areas provided at each stop used by the platoon of buses.
- *Bus Stop Location.* As discussed in the bus stop section above, far-side stops allow for the highest bus lane capacity, but other factors must also be considered when siting bus stops.

Person Capacity

Person capacity is commonly calculated for three locations:

- Bus stops;
- Bus routes, at the maximum load point; and
- Bus lanes, at the maximum load point.

Figure 3 shows, in addition to the factors discussed in the previous section relating to vehicle capacity, other factors that must be considered when calculating person capacity.

Operator Policy

Two factors directly under the control of the bus agency are the maximum *passenger load* allowed on buses and the *service frequency.* An agency whose policy requires all passengers to be seated will have a lower potential passenger capacity for a given number of buses than one whose policy allows standees. (The quality of service experienced by passengers, though, will be higher with the first operator.) The bus frequency determines how many passengers can actually be carried, even though a bus stop or lane may be physically capable of serving more buses than are actually scheduled.

Passenger Demand Characteristics

How passenger demand is distributed spatially along a route and how it is distributed over time during the analysis

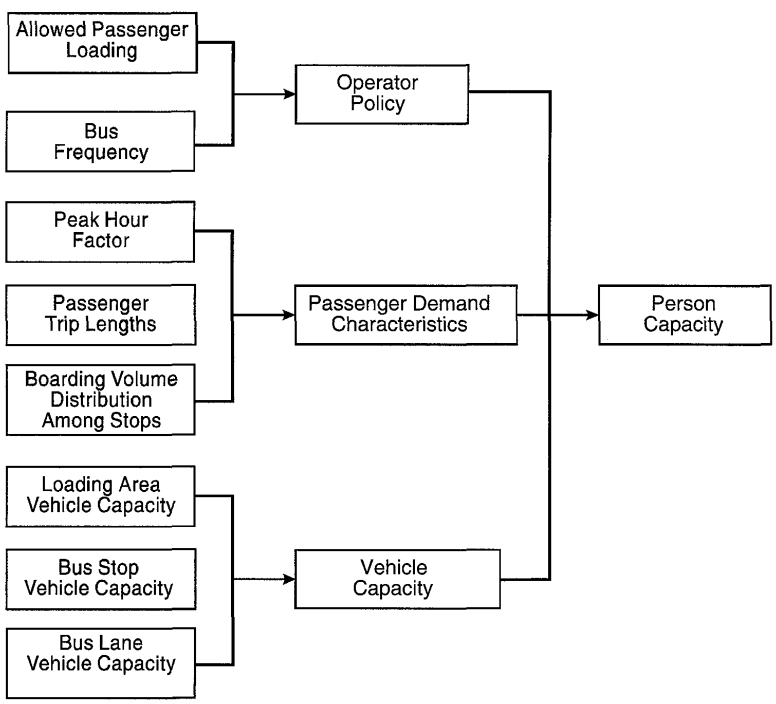

Figure 3. Person capacity factors.

period affects the number of boarding passengers that can be carried. The spatial aspect of passenger demand, in particular, is why passenger capacity must be stated *for a given location,* not for a route or a street as a whole.

During the period of an hour, passenger demand will fluctuate. The *peak hour factor* reflects passenger demand volumes over (typically) a 15-min period during the hour. A bus system should be designed to provide sufficient capacity to accommodate this peak passenger demand. However, because this peak demand is not sustained over the entire hour and because not every bus will experience the same peak loadings, actual person capacity during the hour will be less than that calculated using peak-within-the-peak demand volumes.

The average *passenger trip length* affects how many passengers may board a bus as it travels its route. If trip lengths tend to be long (passengers board near the start of the route and alight near the end of the route), buses on that route will not board as many passengers as a route where passengers board and alight at many locations. However, the total number of passengers on board buses on each route at their respective maximum load points may be quite similar.

The *distribution of boarding passengers* among bus stops affects the dwell time at each stop. If passenger boardings are concentrated at one stop, the vehicle capacity of a bus lane will be lower, because that stop's dwell time will control the vehicle capacity (and, in turn, the person capacity) of the entire lane. Vehicle capacity (and person capacity at the maximum load point) is greater when passenger boarding volumes (and, thus, dwell times) are evenly distributed among stops.

Vehicle Capacity

The vehicle capacity of various facilities used by buses--loading areas, bus stops, and bus lanes--set an upper limit to the number of passengers that may use a bus stop or may be carried past a bus route's or bus lane's maximum load point.

SECTION 3

RAIL TRANSIT CAPACITY BASICS

INTRODUCTION

Part 3 of the TCQSM develops an initial framework to analyze and determine the capacity of rail transit modes in North America. Throughout Part 3, capacity analysis is divided into two methods. The first, the *simple method,* is an easy-to-use procedure for calculating capacity. The second, the *complete method,* adds more variables and is designed for the experienced user who wishes to review rail transit capacity in alternate scenarios--for example: changes in seating arrangements or other aspects of interior car design or light rail with high or low loading, single-track sections, or with or without traffic signal pre-emption.

The procedures in both methods include the rail transit operations variables that affect capacity. The procedures compensate for the differences between *design* capacity and *achievable* capacity--the actual sustainable peak hour capacity. Part 3 chapters and appendixes are as follows:

- Chapter 1 introduces the basic factors and concepts that determine rail capacity.
- Chapter 2 discusses the separation capabilities of various rail transit train control systems.
- Chapters 3 and 4 discuss station dwell times and passenger loading and space requirements.
- Chapter 5 discusses operating issues that influence rail transit capacity.
- Chapters 6 through 9 discuss issues related to grade-separated systems capacity, light rail capacity, commuter rail capacity, and automated guiding transit capacity.
- Chapter 10 contains references for materials presented in Part 3 of the TCQSM.
- Chapter 11 presents example problems that demonstrate how to apply the capacity procedures presented in Part 3 of the TCQSM.
- Appendix A provides substitute exhibits in U.S. customary units for Part 3 exhibits that use metric units.

GROUPING

For capacity analysis, heavy rail, light rail, commuter rail, and automated guideway transit are grouped into unique categories based on alignment, equipment, train control, and operating practices.

The first category is fully segregated, signaled, double-track right-of-way, operated by electrically propelled multiple-unit trains. This is the largest category encompassing all rail rapid transit, including automated routes; several light rail sections (for example, the Market Street subway in San Francisco); and several commuter rail lines. This category is termed Grade-Separated Rail.

The second category is light rail without fully segregated tracks, divided into on-street operations and reserved right-of-way with grade crossings. Streetcar-only operations (Toronto and New Orleans) form a subset of the on-street section.

The third category is commuter rail other than services in category one.

The fourth category includes automated guideway transit routes intended to serve a single major activity center. Although most automated guideway transit is a subset of the main category, Grade-Separated Rail, with very short trains, the use of offline stations--on certain systems--is unique to this mode and requires separate examination. Offline stations can also increase the capacity of more conventional rail transit as discussed in Part 3, Chapter 5, Operating Issues, of the TCQSM.

Each of these categories is provided with its own section with procedures for determining capacity: Chapter 6, Grade-Separated Systems Capacity; Chapter 7, Light Rail Capacity; Chapter 8, Commuter Rail Capacity; and Chapter 9, Automated Guideway Transit Capacity.

THE BASICS

Many rail transit capacity calculations add constants, multipliers, reductive factors, or other methods to correlate theory with practice. In the TCQSM, emphasis has been placed on reducing the number of qualifications and quantifying, describing, and explaining adjustments between theory and practice in determining rail transit capacity.

The TCQSM uses two definitions of capacity: design capacity and achievable capacity.

Design Capacity is the maximum number of passengers past a single point in an hour, in one direction on a single track. Design capacity is similar to, or the same as, *maximum capacity, theoretical capacity,* or *theoretical maximum capacity--expressions* used in other work. It makes no allowance for whether those passenger spaces going by each hour will be used--they would be fully used only if passengers uniformly filled the trains throughout the peak hour. This does not occur and a more practical definition is required. Achievable capacity takes into account that demand fluctuates over the peak hour and that not all trains--or all cars of a train--are equally and uniformly full of passengers.

Achievable Capacity is the maximum number of passengers that can be carried in an hour in one direction on a single track allowing for the diversity of demand. Achievable capacity (sometimes called practical capacity) refers to capacity in one direction on a single track. This is necessary given that most trunk routes in New York have three or four tracks while the Broad Street subway in Philadelphia and the North Side elevated in Chicago have four tracks. The capacity of four-track lines is not a simple multiple of two single tracks and varies widely with operating practices such as the merging and dividing of local and express services and trains holding at stations for local-express transfers. The result is that four tracks do not necessarily increase capacity by as much as expected. A third express track does not necessarily increase capacity at all when restricted to the same station close-in limitations at stations with two platform faces.

Design capacity has two factors--line capacity and train capacity. Line capacity is related to train separation and dwell time at the controlling stations. Train capacity is governed by the number of cars per train and the acceptable level of passenger loading. Achievable capacity is the design capacity modified by a peak hour factor that is determined empirically. Equations for calculating these values are provided in Part 2 of the TCQSM.

The number of trains per hour is the inverse of the closest or minimum headway. It determines train throughput at the controlling station--usually the maximum load point station. In rare cases, speed restrictions or heavy mixed passenger flows may dictate that other than the maximum load point station controls train throughput. The relevant minimum train separation in seconds is the minimum time from when a train starts to leave the most restrictive station, usually the maximum load point station, until the following train can berth at that station. This is referred to as the "close-in" time and is based on *non-interference* with the following train (i.e., no speed restrictions or stops). In a few cases, the critical governor of headway is a junction or a terminal maneuver.

Controlling dwell time is based on actual station dwell time adjusted to a controlling value over the peak hour. The controlling dwell time may contain an operating margin or a margin can be added separately to the denominator of the expression.

DESIGN VERSUS ACHIEVABLE CAPACITY

The TCQSM provides guidelines and methods that can be used for real-world evaluation of rail transit capacities. The difference between *design* and *achievable* capacity is an important consideration.

Design capacity, in passengers per hour per direction (pphpd), is calculated using the following factors:

- Number of seats per car,
- Number of standees per car (= standing area x standee density),
- Number of cars per train, and
- Train headway (minimum headway determined by a combination of the signaling system, station dwell, and terminus constraints).

This approach does not incorporate the following factors that can *reduce* the *actual* number of regular riders that the system can sustain:

- Standing densities vary; people will crowd in more tightly in some situations than in others.
- In a multi-car train, some cars carry more passengers on average than others.
- Many factors reduce train performance (e.g., propulsion faults or differences, door problems, or operator variation), which may not only increase the sustainable average headway, but will increase the variation in headway and consequently, the passenger load waiting for that train.

- Minimum headway, by definition, leaves no margin for schedule recovery from even minor delays, leaving the system susceptible to more variation in service.
- Passenger demand is unevenly distributed within the peak period; there may be predictable "waves" of demand, corresponding to specific work start and finish times. The capacity rate requirement for the peak 10 to 15 min may have to be higher than the average for the peak 1 or 2 hr.
- There is day-to-day fluctuation in demand. Some may be associated with the day of the week (peaks have become lighter on Mondays and Fridays as more people move into shorter or flexible work weeks), seasonally (lighter in the summer and at Christmas time), weather, and special events.
- Passengers are resilient to a degree and will tolerate overcrowding or delay on occasion. This permits systems at capacity to accommodate special events or recover from service delays.

Achievable capacity is the product of the *design* (maximum) capacity and a series of "reality" factors, which adjust the ideal capacity. These factors are not absolutes--they reflect human perception and behavior, as well as site-specific differences (e.g., expectations, cultural attitudes, and the transportation alternatives). The TCQSM has derived these factors from observation of existing U.S. and Canadian rail rapid transit operations to create a single *diversity* or *peak hour factor.* Part 3, Chapter 4, Passenger Loading Levels, details existing peak hour factors and recommends factors for new systems.

Service Headway

Design (minimum) train operating headway is a function of the following:

- Signaling system type and characteristics, including block lengths and separation;
- Operating speed at station approaches and exits or other bottlenecks such as junctions; and
- Train length and station dwell times.

Achievable headway must account for additional factors that can affect the separation of individual trains. These include differences in operator and rolling stock performance, external factors (e.g., grade crossings) that can impose delays, and the need for schedule recovery time.

Station dwell times combine with minimum operating headway to create a constraining headway bottleneck in the system. Typically, this is a concern on fully segregated systems that are operating long trains on close headways. Busy stations, especially major passenger interchanges, can produce block occupancy times that limit the entire system.

Line Capacity

Line capacity is the maximum number of trains that can be operated over a line in a peak hour.

As shown in Figure 4, throughput of the train control system and dwell time at stations are the two major factors in determining line capacity.

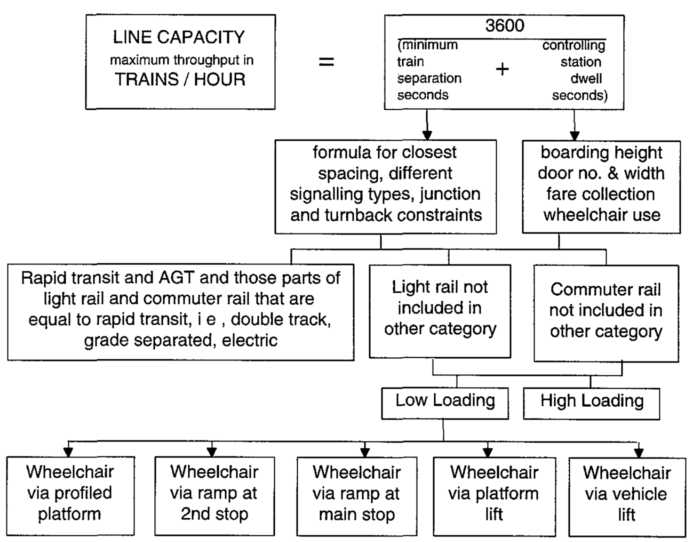

Figure 4. Line capacity flowchart.

Both factors can be divided into the three categories on the basis of alignment, equipment, train control, and operating practices. In turn, light rail and commuter rail lines must be divided by high or low loading and by the method of handling wheelchairs.

Train Control Throughput

The number of trains per hour theoretically possible depends on the particular signaling systems, including the following:

- Conventional block signaling;
- Block signaling with short blocks, overlapping blocks, or *ghost* overlays to decrease headways; and
- Communication- or transmission-based signaling systems with moving blocks.

Chapter 2 of Part 3 in the TCQSM describes different signalizing systems and develops empirical methods to estimate their throughput.

Commuter Rail Throughput

Certain line capacity issues are specific to commuter rail operation. Commuter rail signaling generally is of standard railroad operation and must accommodate trains of different lengths and speeds. Contract operations may set limits on the number of trains per hour.

Station Dwell Times

Station dwell times and train control system minimum separation are the two major factors in determining line capacity. In many circumstances, dwell times are the dominant factor. Another factor is any operational allowance or margin. In some cases, this margin can be added to the dwell time to create a *controlling dwell* time. The three main components of dwell times are as follows:

- Passenger flow time,
- Door open time after flow ceases, and
- Waiting to depart time after doors close.

These components vary widely from system to system.

Commuter Rail Dwell Times

Dwell times on many commuter rail lines are set by schedule or policy and can be relatively independent of passenger flows, although the schedule may be based on anticipated passenger flow times. As a result, passenger flow times on commuter rail can have a lesser effect on capacity than occurs on other modes.

TRAIN/CAR CAPACITY

Introduction

Train capacity is the product of passengers per car and the number of cars, adjusted to achievable capacity using a diversity factor to compensate for uneven car loadings over multiple-car trains (see Figure 5).

Car capacity is often quoted at the crush-loading level, but such loading levels are rarely achieved in practice in the U.S. and Canada, but represent the load for which a car's structure, propulsion, and braking systems are designed.

The only true means of measuring achievable car capacity is on those systems where pass-ups occur (i.e., where

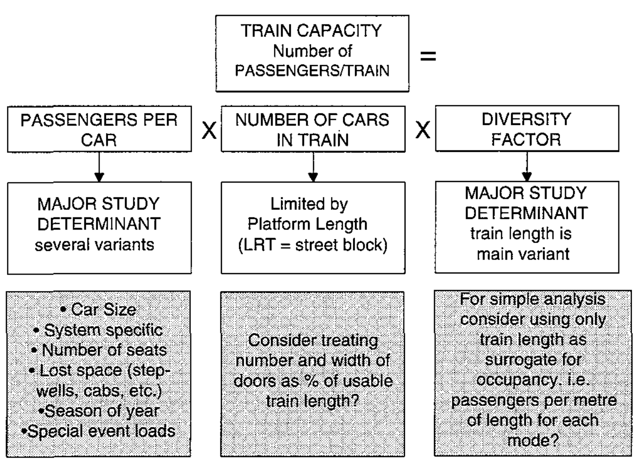

Figure 5. Train capacity flowchart.

passengers wait for the next train rather than crowd onto the one in their station). Determining full car capacity and pass-up capacity depends on interior arrangements, type of system, age of system, and time of peak loading.

Car Capacity

There are two approaches to the calculation and evaluation of car capacity--design specific and a generic average based on car length.

Design-Specific Capacity

If a specific car design has already been chosen, capacity calculation is relatively straightforward. Space used for seats, cabs, wheelchair, stroller or bicycle positions, baggage racks, stepwells, and other equipment is deducted from the interior floor area and the remaining, "standing" space assigned an appropriate standing density.

Train Length Alternative

This alternative offers the simplest method of establishing capacity per unit of car length based on policy decisions of seating type and quantity and standing density. This method is developed and charts provided to determine capacity in Part 3, Chapter 4, Passenger Loading Levels.

Train Capacity

Design train capacity is simply the product of car capacity and the number of cars per train. The number of cars is limited by platform length, or, for light rail with on-street operation, by the shortest city block length.

Achievable capacity is affected by variations in loading along the train--train loading diversity. Existing loading diversities are tabulated in Chapter 4, Passenger Loading Levels, and levels are recommended for use in calculating achievable capacity.

Station Constraints

In rare cases, station capacity constraints can reduce achievable capacity by limiting the flow of passengers to the platform and trains.

TRAIN CONTROL AND SIGNALING

The role of signaling is to safely separate trains from each other and protect specific paths through interlockings at junctions and crossovers. Additional functions include automatic train stops should a train run through a stop signal and speed control to protect approaches to junctions, sharp curves, and approaches to terminal stations where tracks end at a solid wall.

Rail transit signaling maintains high levels of safety based on brick wall stops and fail-safe principles ensuring that no single failure--and often multiple failures--should allow an unsafe event. The rigor with which fail-safe principles have been applied to rail transit has resulted in an exceptional safety record. However, the safety principles do not protect against all possibilities, including possible human errors. An increasing inability to control the human element--responsible for three-quarters of rail transit accidents or incidents--has resulted in new train control systems using automation to reduce or remove the possibility of human error.

Automatic train control adds further features to the train protection of basic signaling, including automatic driving and train supervision that regulates service.

Chapter 2 of Part 3 in the TCQSM describes and compares the separation capabilities of various rail transit train control systems. It is applicable to the main rail transit grouping of electrically propelled, multiple-unit, grade-separated systems.

All urban rail transit train control systems are based on dividing the track into blocks and ensuring that trains are separated by a suitable and safe number of blocks. Train control systems are then broken down into fixed-block and moving-block signaling systems.

Fixed-Block Systems

In a fixed-block system, trains are detected by the wheels and axles of a train shorting a low-voltage current inserted into the rails. The rails are electrically divided into blocks. The blocks will be short where trains must be close together (e.g., in a station approach), and can be longer between stations where trains operate at speed.

The signaling system only knows the position of a train by the simple measure of block occupancy. It does not know the position of the train within the block; it may have only a fraction of the train, front or rear, within the block. At block boundaries, the train will occupy two blocks simultaneously for a short time.

In the simplest two-aspect block system, the signals display only stop (red) or go (green). A minimum of two empty blocks must separate trains and these blocks must be long enough for the braking distance plus a safety distance. The simplest system can accommodate a throughput approaching 24 trains per hour. This does not provide sufficient capacity for some high-volume rail lines. Higher capacity can be obtained from combinations of additional signal aspects (three is typical), shorter block lengths, and overlay systems that electronically divide blocks into yet shorter "phantom" sections--for trains equipped for this overlay.

In this way, conventional train control systems can support a throughput of up to 30 trains per hour with typical train length, performance, station dwell times, and operating margins. Overlay systems can increase this throughput by 10 to 15 percent.

Cab Signaling

Cab signaling uses codes inserted into each track circuit and detected by an antenna on each train. The code specifies the maximum allowable speed for the block occupied and may be termed the *reference* or *authorized* speed. This speed is displayed in the driver's cab--often so that the authorized speed and actual speed can be seen together.

The authorized speed can change while a train is in a block, as the train ahead proceeds, allowing drivers to adjust train speed close to the optimum with less concern about overrunning a trip stop. Problems with signal visibility on curves and in inclement weather are reduced or eliminated. Cab signaling avoids much of the capital and maintenance costs of multiple-aspect color light signals, although it is prudent and usual to leave signals at interlockings and occasionally on the final approach to and exit from each station.

Reducing the number of color light signals makes it economically feasible to increase the number of aspects and it is typical, although not universal, to have the equivalent of five aspects on a cab signaling system. A typical selection of *reference* speeds would be 80, 70, 50, 35, and 0 km/h (50, 43, 31, 22, and 0 m/h).

Moving-Block Signaling Systems

Moving-block signaling systems are also called transmission-based or communication-based signaling systems. A moving-block signaling system can be compared with a fixed-block system with very small blocks and a large number of aspects. However a moving-block signaling system has neither blocks nor aspects. The system is based on a continuous or frequent calculation of the clear (safe) distance ahead of each train and then relaying the appropriate speed and braking or acceleration rate for each train.

This requires a continuous or frequent two-way communication with each train and a precise knowledge of a train's location, speed, and length and fixed details of the line (i.e., curves, grades, interlockings, and stations). On the basis of this information, a computer can calculate the next stopping point of each train--often referred to as the target point--and command the train to brake, accelerate, or coast accordingly. The target point will be based on the normal braking distance for that train plus a safety distance.

The safety distance is the maximum distance a train can travel after it has failed to act on a brake command before automatic override (or overspeed) systems implement emergency braking.

Without track circuits to determine block occupancy, a moving-block signaling system must have an independent method to accurately locate the position of the front of a train, then use look-up tables to calculate its end position from the length associated with that particular train's identification. The first moving-block systems used a wire laid alongside or between the running rails periodically transposed from side-to-side.

The use of exposed wayside wires is a maintenance problem and refinements use inert transponders located periodically along the track. These are interrogated by a radio signal from each train and return a discrete location code. Positioning between transponders relies on the use of a tachometer. Communications to and from the train are then radio-based with protocols to ensure safety and reliability and that messages are received by and only by the train they are intended for.

The computers that calculate and control a moving-block signaling system can be located on each train, at a central control office, dispersed along the wayside, or a combination of these. The most common arrangement is a combination of on-board and central control office locations.

Safety Issues

Safety on rail transit is a relative matter. It encompasses all aspects of design, maintenance, and operations. In fixed-block signaling, electrical interlockings, switch, and signal setting are controlled by relay logic. A rigorous discipline has been built around this long-established technology, which the use of processor-based controls is now infiltrating.

A moving-block signaling system is inherently processor-controlled. Processor-based train control systems intrinsically cannot meet the fail-safe conventions of traditional signaling. Computers, microprocessors, and solid-state components have multiple failure opportunities and cannot be analyzed and tested in the same way as conventional equipment.

Instead, an equivalent level of safety is provided based on statistical failure modes of the equipment. Failure analysis is not an exact science. Although not all failure modes can be determined, the statistical probability of an unsafe event[1] can be predicted.

HYBRID SYSTEMS

There are times when an urban rail transit system shares tracks with other services, such as long-distance trains, whose equipment is impractical or uneconomical to equip with the moving-block signaling system. Hybrid or overlay

[1] An unsafe event may be referred to as a wrong-side failure.

systems are available that allow use by unequipped trains--with longer separation--while still obtaining the close headway of the moving-block system for the urban or short distance trains.

Automatic Train Operation

Automatic acceleration has long been a feature of rail transit, where relays and, more recently, microprocessors control the rate of acceleration smoothly from the initial start to maximum speed. Linking this feature to on-board commands from the signaling system provides automatic train operation.

The driver or attendant' s role is typically limited to closing the doors, pressing a train start button, and observing the line ahead, with limited manual operating capabilities to deal with certain failures. Dispensing entirely with a driver or attendant is controversial but has demonstrated its economy and safety on numerous Automated Guideway Transit (AGT) systems and on rail transit systems in Europe and Vancouver, B.C., Canada.

Automatic train operation (ATO), with or without attendants or drivers, allows a train to more closely follow the optimum speed envelope and commence braking for the final station approach at the last possible moment. This reduces station-to-station travel times and, more importantly from the point of capacity, it minimizes the critical station close-in time--the time from when one train starts to leave a station until the following train is berthed in that station. This can increase total line capacity by 2 to 4 percent.

SECTION 4

TERMINAL CAPACITY BASICS

INTRODUCTION

Part 4 of the TCQSM contains procedures for estimating the capacities of various elements of transit terminals. For bus stops, guidelines for sizing passenger waiting areas at stops and for selecting passenger amenities within these areas are provided. For bus and rail stations, procedures are provided for sizing outside transfer facilities, such as bus transfer, park-and-ride, and kiss-and-ride areas, as well as the various inside terminal elements, such as walkways, stairways, escalators, elevators, turnstiles, ticket machines, and platforms.

Although previous efforts have involved designing terminal facilities based on maximum pedestrian capacity, research has shown that a breakdown in pedestrian flow occurs when there is a dense crowding of pedestrians, causing restricted and uncomfortable movement. For this reason, many of the procedures contained in this chapter for sizing terminal elements are based on maintaining a desirable pedestrian level of service and use the pedestrian level of service analysis procedures also documented in the HCM.

For larger terminals, the different pedestrian spaces interact with one another such that capacity and level of service might better be evaluated from a systems perspective. The use of simulation models to assess the effect of queue spillback on downstream facilities can be applied to size overall internal spaces within a terminal facility and, thus, the application of simulation models is discussed in this part of the TCQSM.

BUS STOPS

Passenger Waiting Areas

The recommended procedures for computing the size of passenger waiting areas at bus stops are based on maintaining a desirable level of service. The concept of pedestrian level of service is presented in the *Highway Capacity Manual.* The primary measure of effectiveness for defining pedestrian level of service is the average space available to each pedestrian. The level of service for a pedestrian waiting area is based not only on space but also the degree of mobility allowed. In dense standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases.

Studies have shown that pedestrians keep as much as a 0.4-m (18-in.) buffer between themselves and the edge of curb. This suggests that the effective width of a typical bus stop should be computed as the total width minus 0.4 m (18 in.).

Level-of-Service Standards

Level-of-service descriptions for passenger waiting areas are shown in Table 3. The standards were developed on the basis of average pedestrian space, personal comfort, and degrees of internal mobility. The standards are presented in terms of average area per person and average interpersonal space (distance between people).

The level of service required for waiting within a facility is a function of the amount of time spent waiting and the number of people waiting. Typically, the longer the wait, the greater the space per person required. Also, the required space per person may vary over time. For example, those waiting in the beginning will want a certain amount of space initially, but will be willing to accept less space as additional people arrive later.

A person's acceptance of close interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, commuters may be willing to accept higher levels or longer periods of crowding than recreational travelers.

TABLE 3 Levels of service for opening areas

Level Of Service	Average Pedestrian Area	Average Inter-Person Spacing	Description
A	≥ 1.2 m^2 (13 ft^2) per person	≥ 1.2 m (4 ft)	Standing and free circulation through the queuing area possible without disturbing others within the queue.
B	0.9-1.2 m^2 (10-13 ft^2) per person	1.1-1.2 m (3.5-4 ft)	Standing and partially restricted circulation to avoid disturbing others within the queue is possible.
C	0 7-0.9 m^2 (7-10 ft^2) per person	0.9-1.1 m (3-3.5 ft)	Standing and restricted circulation through the queuing area by disturbing others is possible; this density is within the range of personal comfort.
D	0.3–0.7 m^2 (3-7 ft^2) per person	0 6–0.9 m (2-3 ft)	Standing without touching is impossible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is discomforting.
E	0.2- 0.3 m^2 (2-3 ft^2) per person	≤ 0.6 m (2 ft)	Standing in physical contact with others is unavoidable; circulation within the queue is not possible; queuing at this density can only be sustained for a short period without serious discomfort.
F	≤ 0.2 m^2 (2 ft^2) per person	Close contact	Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely discomforting; no movement is possible within the queue; the potential for panic exists.

Determining Required Passenger Waiting Area

As discussed above, the procedures to determine passenger waiting area at bus stops are based on maintaining a desirable pedestrian level of service. For most bus stops, the design level of service should be C to D or better. The following list of steps is recommended for determining the desired bus stop size:

1. Based on the desired level of service, choose the average pedestrian space from Table 3.
2. Estimate the maximum demand of passengers waiting for a bus at a given time.
3. Calculate the effective waiting area required by multiplying the average pedestrian space by the maximum pedestrian demand.
4. Calculate the total required waiting area by adding a

0.4-m-(18-in.)-buffer width (next to the roadway) to the effective waiting area.

IMPACT OF PASSENGER AMENITIES

Passenger amenities are those elements provided at a bus stop to enhance comfort, convenience, and security for the transit patron. Amenities include such items as shelters, benches, vending machines, trash receptacles, phone booths, information signs or kiosks, bicycle racks, lighting, and landscaping. The effects that particular amenities have on transit ridership and passenger waiting area capacity is unclear. Amenities at most bus stops are placed in response to a human need or a need to address an environmental condition. The advantages and disadvantages of different passenger amenities at bus stops are summarized in Table 4.

Overall required passenger waiting areas at bus stops should account for space taken up by shelters, benches, information signs and other amenities, with appropriate shy distances.

RAIL AND BUS STATIONS

Outside Transfer Facilities

Bus Berths

A critical component at major bus and rail stations is the provision of bus transfer areas where buses serving the station can board and alight passengers. For most stations, the bus transfer area consists of an off-street bus berthing area near or adjacent to the station building or platform area. For small transit stations, the number of berths (loading areas) is small with a fairly simple access and layout configuration. For larger terminals, numerous berths and more sophisticated designs are applied.

Four types of bus berthing are typically applied:

- Linear,
- Sawtooth,
- Angle, and
- Drive-through.

Linear berths can operate in series and have capacity characteristics similar to on-street bus stops. Angle berths are limited to one bus per berth, and they require buses to back out. Drive-through angle berths are also feasible and may accommodate multiple vehicles. Shallow "sawtooth" berths are popular in urban transit centers and are designed to permit independent movements into and out of each berth. The National Transportation Safety Board recommends that transit facility designs incorporating sawtooth berths or other types of berths that may direct errant buses toward pedestrian-occupied areas include provisions for positive separation (such as bollards) between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area.

TABLE 4 Examples of passenger amenities at bus stops

Amenity	Advantages	Disadvantages
Shelters	• Provide comfort for waiting passengers • Provide protection from climate-related elements (sun, glare, wind, rain, snow) • Help identify the stop	• Require maintenance, trash collection • May be used by graffiti artists
Benches	• Provide comfort for waiting passengers • Help identify the stop • Low cost when compared with installing a shelter	• Require maintenance • May be used by graffiti artists
Vending Machines	• Provide reading material for waiting passengers	• Increase trash accumulation • May have poor visual appearance • Reduce circulation space • Can be vandalized
Lighting	• Increases visibility • Increases perceptions of comfort and security • Discourages "after hours" use of bus stop facilities by indigents	• Requires maintenance • Can be costly
Trash Receptacles	• Provide place to discard trash • Keep bus stop clean	• May be costly to maintain • May be used by customers of nearby land use (i.e., fast-food restaurant) • May have a bad odor
Telephones	• Convenient for bus patrons • Provide access to transit information	• May encourage loitering at bus stop • May encourage illegal activities at bus stop
Route or Schedule Information	• Useful for first-time riders • Helps identify bus stop • Can communicate general system information	• Must by maintained to provide current information • May be used by graffiti artists

Capacity Characteristics. Table 5 identifies the maximum linear berthing capacity for bus berths in terminals not affected by on-street signals or traffic and without major layovers.

For larger bus stations and for bus routes laying over or terminating at a station, typical design practice is to provide for individual berths for each route. In this case, bus dwell times are typically longer than the 2-min ceiling applicable to Table 5, and the number of berths required per route will be driven by the longer dwell time.

As indicated in Part 2 of the TCQSM, providing additional space within a linear bus berth configuration increases the overall berth capacity, but at a decreasing rate as the number of loading areas increases. Each loading area at a multiple-berth stop does not have the same capacity as a single-berth stop, because it is not likely that the loading areas at a multiple-berth stop will be equally used or that passengers will distribute equally among loading positions. Moreover, where stops are designated for specific routes, bus schedules may not permit an even distribution of buses among loading positions. Buses may also be delayed in entering or leaving a berth by buses in adjacent loading positions.

Suggested berth efficiency factors are given in Table 6 for offline linear berths at bus terminals. These factors are based on experience at the Port Authority of New York and New Jersey's Midtown Bus Terminal. The table suggests that four or five online positions could have a maximum efficiency of 2.5 berths. Five offline positions would have an efficiency of about 3.75 berths. To provide two "effective" berths, *three* physical berths would need to be provided, because partial berths are never built. All other types of multiple berths are 100 percent efficient--the number of effective berths equals the number of physical berths.

Park-and-Ride Facilities

At selected transit stations, park-and-ride facilities for automobiles are provided. Park-and-ride facilities are primarily located at the outer portions of a rail line or busway, in the outer portions of central cities, and in the suburbs in urban areas. At most locations, these facilities are integrated with bus transfer facilities. The size of park-and-ride facilities can vary from as little as 10 to 20 spaces at minor stations to more than 1,000 spaces at major stations. The design of these facilities is similar to other off-street parking facilities. Most park-and-ride facilities are surface lots, with pedestrian connections to the transit station. Parking structures are used where land is at a premium and where a substantial number of parking spaces are required.

Kiss-and-Ride Facilities

Kiss-and-ride facilities are automobile pickup and dropoff areas provided at transit stations where transit patrons are dropped off and picked up by another person in a vehicle. Parking needs associated with this concept are associated with vehicles waiting to pick up transit riders, with the dropoff requiring no parking maneuver (though curb space is needed to handle the dropoff). As with park-and-ride facilities, the sizing of kiss-and-ride facilities reflects the demand and site physical constraints. Many larger transit stations provide dedicated kiss-and-ride facilities. In Toronto, an innovative "carousel" design has been applied at several stations where a separate inside terminal facility has been developed for transit riders to wait to be picked up, with direct access to the rail station.

Inside Terminal Elements

An important objective of a transit station is to provide adequate space and appropriate facilities to accommodate projected peak pedestrian demands while ensuring pedestrian safety and convenience. Previous efforts have involved designing transit stations on the basis of maximum pedestrian capacity without consideration of pedestrian convenience. Recent research has shown, however, that capacity

TABLE 5 Estimated maximum vehicle capacity of station linear bus berths under low dwell time conditions

Dwell Time (s)	Bus/h
15	116
30	69
45	49
60	38
75	31
90	26
105	23
120	20

NOTE: Assumes 10-sec clearance time, 25 percent queue probability, and 60 percent coefficient of variation.

TABLE 6 Efficiency of multiple linear off-line bus berths at bus terminals

Berth No.	Efficiency (%)	No. of Cumulative Effective Linear Berths
1	100	1.00
2	85	1.85
3	75	2.60
4	65	3.25
5	50	3.75

is reached when there is dense crowding of pedestrians, causing restricted and uncomfortable movement

The capacity procedures presented are based on a relative scale of pedestrian convenience. Procedures for evaluating pedestrian capacity and level of service are contained in the 1997 HCM and in Fruin, J.J., *Pedestrian Planning and Design,* Elevator-World, Inc., Mobile, Alabama, 1987. Those procedures that relate to transit station design are summarized in the following sections.

Pedestrian Capacity Terminology

Terms used in this chapter for evaluating pedestrian capacity are defined as follows:

- *Pedestrian speed:* average pedestrian walking speed, generally expressed in units of meters or feet/second.
- *Pedestrian flow rate:* number of pedestrians passing a point per unit time, expressed as pedestrians per 15 minutes or pedestrians per minute; "point" refers to a perpendicular line of sight across the width of roadway.
- *Unit width flow:* average flow of pedestrians per unit of effective walkway width, expressed as pedestrians per minute per meter or foot.
- *Pedestrian density:* average number of pedestrians per unit of area within a walkway or queuing area, expressed as pedestrians per square meter or foot.
- *Pedestrian space:* average area provided for each pedestrian in a walkway or queuing area, expressed in terms of square meters or feet per pedestrian; this is the inverse of density, but is a more practical unit for the analysis of pedestrian facilities.

Pedestrian Level of Service

Level-of-service standards provide a useful means of determining the environmental quality of a pedestrian space. Pedestrian service standards related to walking are based on the freedom to select desired walking speeds and the ability to bypass slower moving pedestrians. Other measures related to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, and to maneuver without conflicts and changes in walking speed.

Level of service standards for queuing areas are based on available standing space and the ability to maneuver from one location to another. Because pedestrian level of service standards are based on the amount of pedestrian space available, these standards can be used to determine desirable design features such as platform size, number of stairs, and corridor width.

Pedestrian System Requirements

Pedestrian flow is related to the width of the walkway, pedestrian density, and walking speed. An initial step in evaluating a transit station design is to outline the pedestrian system requirements. Determining system requirements begins with a detailed description of the pedestrian flow process through a terminal in the form of a flow chart. Properly done, the system diagram serves as a checklist and a constant reminder of the interrelationship of the various functional elements of the station.

After the system requirements have been described schematically, they should be described quantitatively. Often this can be done following the same basic format and sequence as the system description. Pedestrian volumes can be scaled to size and plotted graphically to illustrate volume and direction. Pedestrian walking times, distances, and waiting and service times can also be entered into this diagram.

An essential principle in designing terminals is the balance between pedestrians exiting trains and those arriving on the platform. In order to avoid unsafe crowding conditions, the platform must clear sufficiently between trains during peak period operations. Simulation programs can be used to test various loading conditions.

SECTION 5

QUALITY OF SERVICE

INTRODUCTION

Quality of service reflects the passenger's perception of transit performance. It measures both the availability of transit service and its comfort and convenience. Quality of service depends to a great extent on the operating decisions made by a transit system, especially decisions on where transit service should be provided, how often and how long transit service should provided, and what kind of service should be provided.

Part 5 of the TCQSM presents methods for measuring quality of service.

- Chapter 1 discusses transit performance measures in general and differentiates passenger-based quality of service measures from other kinds of transit performance measures.
- Chapter 2 examines the factors that enter into a potential rider's decision to use transit for a particular trip and introduces a framework for categorizing quality of service measures.
- Chapter 3 presents level-of-service ranges for six quality of service measures addressing transit availability and quality for transit stops, route segments, and systems.
- Chapter 4 discusses applications for the quality of service measures.
- Chapter 5 contains references for material presented in Part 5 that may be consulted for further information regarding transit quality of service.
- Chapter 6 presents example problems that apply quality of service measures to real-world situations.

DEFINITIONS

In the North American transit industry, many definitions are not standardized or are specific to a particular transit system. Caution is needed when using the terms *quality of service* and *level of service,* which have various meanings. *Level of service,* for example, is often used literally to mean the amount of service both in frequency and hours of coverage--the latter sometimes referred to as the "span" of service.

This manual uses the following definitions of transit performance measures, quality of service, service measures, and levels of service:

- *Transit Performance Measure:* a quantitative or qualitative factor used to evaluate a particular aspect of transit service;
- *Quality of Service:* the overall measured or perceived performance of transit service from the *passenger's* point of view;•
- *Transit Service Measure:* a quantitative performance measure that best describes a particular aspect of transit service *and* represents the passenger's point of view (also known as a *measure of effectiveness);* and
- *Levels of Service:* six designated ranges of values for a particular service measure, graded from "A" (best) to "F" (worst) based on a transit passenger's perception of a particular aspect of transit service.

The primary differences between performance measures and service measures are follows:

1. Service measures must represent the passenger's point of view, while performance measures can reflect any number of points of view.
2. In order to be useful to users, service measures should be relatively easy to measure and interpret. It is recognized, however, that systemwide measures will, of necessity, be more complex than bus stop or route segment measures.
3. Level-of-service (LOS) grades are developed only for service measures. However, transit operators are free to develop LOS grades for other performance measures, if those measures would be more appropriate for particular applications.

LEVELS OF SERVICE

The selection of LOS thresholds for each of the service measures presented in the TCQSM represents the collective professional judgment of the TCRP Project A-15 research team and panel. However, the LOS grades--in particular, LOS F--are not intended to set national standards. It is left to local transit operators and policy agencies to decide how to apply the LOS measures. To aid in this effort, the TCQSM provides guidance on the changes in service quality perceived by passengers at each LOS threshold.

TRANSIT PERFORMANCE MEASURES

To get a sense of what quality of service is, it is useful to understand what it is not. Figure 5 illustrates one possible way that transit performance measures can be categorized and shows how quality of service fits into the spectrum of transit performance measures. *TCRP Synthesis 10,* "Bus Route Evaluation Standards," is a useful compilation of performance measures at both the transit route and system levels.

The *passenger point of view,* or *quality of service,* directly measures passengers' perceptions of the availability, comfort, and convenience of transit service. As Figure 5 indicates, several possible performance measures can be used. Those measures that best represent the passengers' perspective of transit availability, comfort, and convenience, yet are relatively easy to measure, have been selected as service measures, as shown by the darker tint. LOS ranges developed for these and other service measures were presented in Chapter 3.

The *operator point of view* encompasses the measures routinely collected in the United States for the FTA's National Transit Database (formerly Section 15) annual reporting process. Most of these measures relate to economy or productivity. These measures are important to the operator

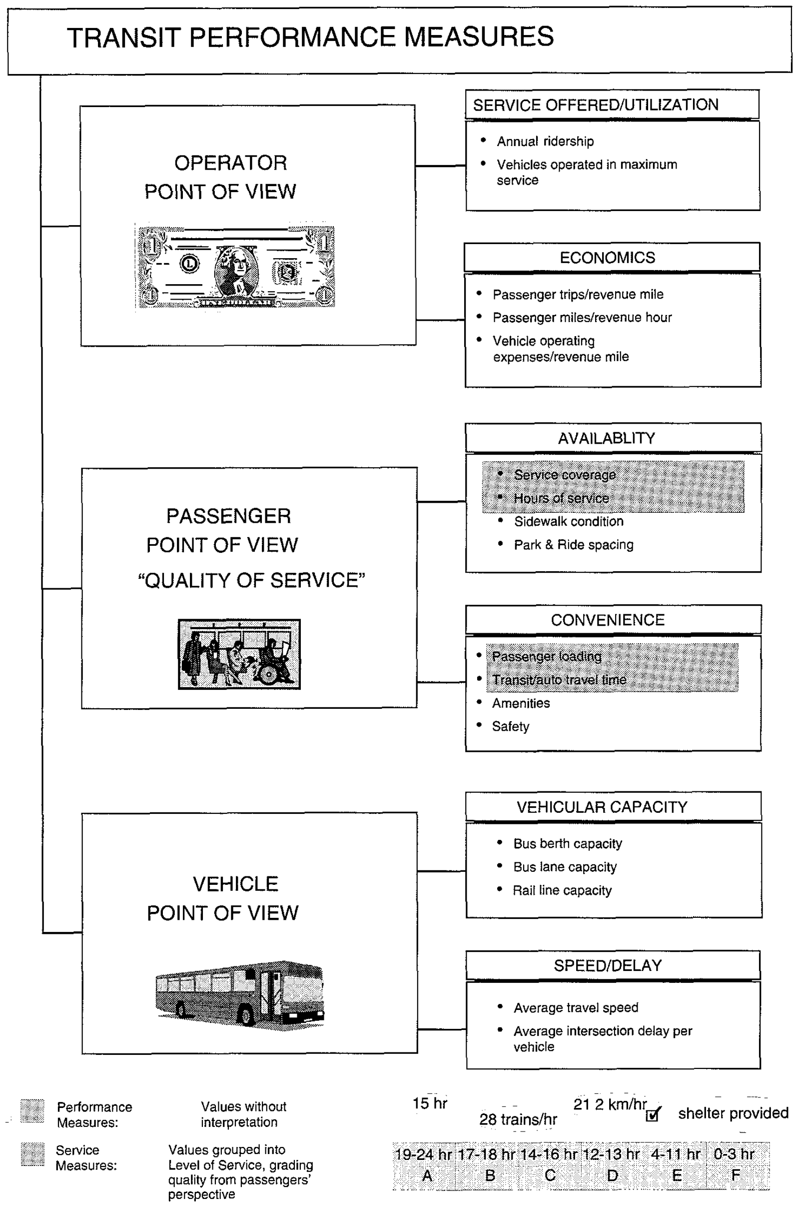

Figure 5. Transit performance measure categories and examples.

--and indirectly to passengers--by reflecting the amount of service an operator can afford to provide on a route or the system as a whole. The productivity measures (e.g., ridership) indirectly measure passenger satisfaction with the quality of service provided. However, only two of these reported operator measures directly relate to the passenger's point of view: (1) actual vehicle revenue hours per directional mile and (2) vehicles operated in maximum service per directional mile. These measure the "amount" of service. The first is an overall system average, while the second is an average of the amount of service provided in the peak period (i.e., when maximum service is deployed).

The *vehicle point of view* includes measures of vehicular speed and delay routinely calculated for streets and highways using the procedures given in the *Highway Capacity Manual.* This point of view also includes measures of facility capacity in terms of the number of transit vehicles that can be accommodated. Because transit vehicles carry passengers, these measures also reflect the passenger's point of view: passengers on-board a transit vehicle traveling at an average speed of 20 km/h (12 mph) individually also experience this same average travel speed. However, because these vehicle-oriented measures do not take passenger loading into account, the passenger point of view is hidden because all vehicles are treated equally, regardless of the number of passengers in each vehicle. For example, while a single-occupant vehicle and a 50-passenger bus traveling on the same street may experience the same amount of delay due to on-street congestion and traffic signal delays, the person-delay experienced by the bus is 50 times as great as the single-occupant vehicle.

In measuring transit quality of service, the size of the city, metropolitan area, "commutershed," or transit service area may need to be taken into account. A small city could regard transit service on a route every 30 min for 12 hr per day, 6 days per week to be good. In a large transit system, good service could require service at least every 10 to 15 min, 18 hr a day, 7 days a week. However, these determinations of "good service" are based as much on passenger demand and the realities of transit operating costs as they are on passengers' perceptions of service quality.

The question arises, should there be different levels of service for different size areas? From purely a passenger's perspective, which quality of service is based upon, the answer is "no": a 1-hr headway between buses is just as long for a passenger in a small town as it is for a passenger in a large city. Therefore, no distinction has been made in the levels of service presented in Chapter 3 to account for area population. (The consequences of providing a 1-hr headway, though, do vary by city size and are reflected by other measures, such as passenger loads. These consequences will be more severe in a large city than in a small city.)

From an operator's standpoint, however, there are significant differences between small towns and large cities, particularly in passenger demand volumes and available funding levels. These differences can be accounted for in the way transit agencies apply the levels of service: a small city agency may set a service frequency goal of LOS E, while a large city agency may set a service frequency target of LOS C. The measure used to determine level of service is the same in both cities; the difference is that one agency sets a higher standard than the other in order to meet its service area's greater needs.

QUALITY OF SERVICE FRAMEWORK

Quality of service measures are divided into two main categories: *availability* and *quality.* The availability measures address the spatial and temporal availability of transit service. If transit is located too far away from a potential user or if it does not run at the times a user requires the service, that user would not consider transit service to be available and thus the quality of service would be poor. Assuming, however, that transit service is available, the quality measures can be used to evaluate a user's perception of the comfort and convenience of his or her transit experience.

Different elements of a transit system require different performance measures. The following categories are used in Chapter 3:

- *Transit Stops.* Measures addressing transit availability and convenience at a single location. Because these measures depend on passenger volumes, scheduling, routing, and stop and station design, performance measures in this category will vary from one location to another.
- *Route Segments.* Measures addressing availability and convenience along a portion of a route, which can range from two stops to the entire length of a route. These measures will tend to stay the same over the length of a route segment, regardless of conditions at an individual stop.
- *Systems.* Measures of availability and convenience for more than one route operating within a specified area (e.g., a district, city, or metropolitan area) or of a specified type (e.g., fixed-route versus demand-responsive). System measures can also address door-to-door travel.

Combining the two performance measure categories with the three transit system elements produces the matrix shown in Table
7. Service measures are shown in capital letters, while other performance measures are shown in lower case. The discussion focuses on the service measures in capital letters because these are the primary measures of availability and quality of service.

Some measures appear in more than one cell of the table, but only one service measure is assigned to each cell, representing the performance measure that best represents the passenger's point of view of availability or convenience for a particular transit element. In many cases, though, it may be helpful to combine the service measures into a kind of transit "report card" that compares several different aspects of transit service at once.

QUALITY OF SERVICE MEASURES

Each quality of service measure has been divided into six levels of service, representing ranges of values for a particular service measure. The following considerations entered into the development of the transit LOS system:

1. *The transit LOS system should use an A-F scale.* A survey of transit operators, cities, counties, metropolitan planning organizations, state departments of transportation, and transit professionals conducted for TCRP Project A-15 found a preference for this system. The benefits of this system are twofold: (1) decision-makers

TABLE 7 Quality of service framework

Category	Service & Performance Measures		
	Transit Stop	Route Segment	System
Availability	FREQUENCY accessibility passenger loads	HOURS OF SERVICE accessibility	SERVICE COVERAGE % person-minutes served indexes
Quality	PASSENGER LOADS amenities reliability	RELIABILITY travel speed transit/auto travel time	TRANSIT/AUTO TRAVEL TIME travel time safety

are already familiar with the A-F scale for highways presented in the *Highway Capacity Manual,* and (2) much of the public is familiar with the A-F scale used for report cards.

2. *The LOS ranges should reflect a user's point-of-view.* LOS A, therefore, is not necessarily representative of optimum conditions from a transit operator's point-of-view.
3. *LOS F should represent an undesirable condition from a user's point-of-view.* A transit operator may choose to set higher standards based on policy goals.
4. *The thresholds for LOS A through E should represent points where a noticeable change in service quality occurs.* As a secondary consideration, it is also desirable to have evenly spaced ranges of values for each LOS grade, to the extent possible.

Thresholds for the LOS presented in this section were derived from TCRP Project A-15. Where appropriate, descriptions of the changes in conditions that occur at LOS thresholds are provided with each service measure.

AVAILABILITY--TRANSIT STOPS

Frequency

From the user's perspective, frequency determines the number of times an hour a user has access to the transit mode, assuming that transit service is provided within acceptable walking distance (measured by *service coverage)* and at the times the user wishes to travel (measured by *hours of service).* Service frequency also measures the convenience of transit service and is one component of overall transit trip time.

Because of the different characteristics of urban scheduled transit service, paratransit service, and intercity scheduled transit service, different measures are used to define LOS for each kind of service, as described below. Frequency LOS can vary by time of day or week: for example, a service may operate at LOS B during peak hours, LOS D midday, and LOS F at night. Similarly, paratransit service may operate at LOS D on weekdays, but at LOS F on weekends if no service is offered.

Urban Scheduled Transit Service

Urban scheduled transit service includes all scheduled service within a city, as well as service between cities within a larger metropolitan area. Deviated-route bus service is included in this category, because the basic service is scheduled, even if specific stops are not. Commuter rail is considered as intercity scheduled transit service, discussed below, for the purposes of determining LOS.

The service frequency LOS measure for urban scheduled transit service is *headway;* however, for convenience, Table 8 lists LOS both by headway and by the corresponding number of vehicles per hour. Although headways are given as continuous ranges for the purposes of determining

TABLE 8 Service frequency LOS: urban scheduled transit service

LOS	Headway (min)	Veh/h	Comments
A	<10	>6	Passengers don't need schedules
B	10-14	5-6	Frequent service, passengers consult schedules
C	15-20	3-4	Maximum desirable time to wait if bus/train missed
D	21-30	2	Service unattractive to choice riders
E	31-60	1	Service available during hour
F	>60	<1	Service unattractive to all riders

LOS, passengers find it easier to understand schedules when clock headways are used (headways that are evenly divisible into 60). When clock headways are used, transit vehicles arrive at the same times each hour.

Service frequency LOS is determined by destination from a given transit stop, as several routes may serve a given stop, but not all may serve a particular destination. Some judgment must be applied to bus stops near timed transfer centers. There is a considerable difference in service from a passenger's perspective between a bus arriving every 10 min and three buses arriving in a row from a nearby transfer center every 30 min, even though both scenarios result in six buses per hour serving the stop. In general, buses on separate routes serving the same destination that arrive at a stop within 3 min of each other should be counted as one bus for the purposes of determining service frequency LOS.

At the service frequencies of LOS A, passengers are assured that a transit vehicle will arrive soon after they arrive at a stop. The delay experienced if one misses a vehicle is low. At LOS B, service is still relatively frequent, but passengers will consult schedules to minimize their wait time at the transit stop. Service frequencies at LOS C still provide a reasonable choice of travel times, but the wait involved if a bus or train is missed becomes long. At LOS D, service is only available about twice an hour and requires passengers to adjust their routines to fit the transit service provided. The threshold between LOS E and F is service once an hour; this corresponds to the typical analysis period and to the minimum service frequency applied when determining hours of service LOS. Service at frequencies greater than 1-hr entails highly creative planning or considerable wasted time on the part of passengers.

Paratransit Service

Paratransit includes all unscheduled transit service where service is obtained by notifying the service provider that a pick-up is desired. However, as noted above, deviated fixed-route service is evaluated using the urban scheduled transit service procedures, because the basic service is scheduled.

The measure of service frequency for paratransit service is *access time,* the minimum amount of time from when a passenger first requests service to the time a pick-up can be guaranteed to occur. Therefore, access time for *standing reservations--where* passengers are picked up every day at a given time, unless the service provider is notified otherwise--is calculated for the situation when a request for service is first made. Table 9 shows service frequency level of service for paratransit.

Paratransit service frequency at LOS A levels provides a ride within 30 min of the request, minimizing the wait time after one decides to make a trip. At LOS B and C, the wait time increases, but travel still requires little or no planning on the part of the passenger. At LOS D, same-day round-trip service is still possible, but generally requires some planning on the part of the passenger. The threshold between LOS E and F is 1 day's advance notice for obtaining a ride. At LOS F, service is only available a few days a week or not at all.

Intercity Scheduled Transit Service

Transportation services between communities can be just as important as services within communities, especially for rural communities where medical, educational, and other services may not be readily available. Intercity transportation services, whether bus, train, or ferry, help fill these mobility needs by linking smaller communities to larger communities and to other transportation modes. Some states recognize rural mobility needs by incorporating goals for minimum intercity service levels in their statewide transportation plans.

The number of *trips per day* between one community and another establishes the level of service for intercity service as shown in Table 10.

At LOS A, passengers have many choices of travel times and have a relatively short wait for the next trip if one bus or train is missed. Service at LOS B and C still provides a good range of travel times, but involve longer waits when a vehicle is missed. At LOS D, only a few trips per day are made between the communities, but one is not forced to wait the entire day at one's destination for the return trip. The threshold between LOS E and F is a minimum of two round trips per day, allowing a return to one's origin the same day, with sufficient time in the destination city for the trip to be useful. With just one round trip a day (LOS F), a transit vehicle would likely return to its origin soon after arriving, not allowing time for one to do anything useful in the destination community and still return home that day.

TABLE 9 Service frequency Paratransit service

LOS	Access Time (h)	Comments
A	0.0-0.5	Fairly prompt response
B	0.6-1.0	Acceptable response
C	1.1-2.0	Tolerable response
D	2.1-4.0	Poor response, may require advance planning
E	4.1-24.0	Requires advance planning
F	>24.0	Service not offered every weekday or at all

TABLE 10 Service frequency LOS: intercity scheduled transit service

LOS	Trips/Day	Comments
A	>15	Numerous trips throughout the day
B	12-15	e.g., midday and frequent peak hour service
C	8-11	e.g., midday or frequent peak hour service
D	4-7	Minimum service to provide choice of travel times
E	2-3	Round trip in one day is possible
F	0-1	Round trip in one day is not possible*

*Technically, a round trip might be possible, but the transit vehicle would likely return to its origin soon after arriving at its destination, not allowing any time for errands.

Other Measures

Accessibility

Pedestrian, bicycle, automobile, and ADA accessibility to transit stops is difficult to quantify. An evaluation of pedestrian accessibility should consider whether or not sidewalks are provided, the condition of the sidewalks, terrain, traffic volumes on streets that pedestrians must cross to access a transit stop and the kind of traffic control provided on those streets, and whether out-of-direction travel is required. One possible measure could be pedestrian travel time to a stop from a point 0.4 km (0.25 mi) away, with different walking times assigned to different walking environments, and accounting for the delays involved with (1) waiting for a WALK indication at signalized intersections and (2) waiting for a sufficiently large gap in traffic to walk across a street at an unsignalized intersection. The *Manual on Uniform Traffic Control Devices* and the ITE *Manual of Transportation Engineering Studies* provide guidance on pedestrian travel speeds and assessing gaps in traffic.

Bicycle access should consider the availability and condition of bicycle facilities on the roadways leading to transit stops, traffic volumes on the roadways leading to transit stops, the provision of bicycle racks on buses and whether demand exceeds bus rack capacity, provision of bicycle storage lockers at high-volume boarding locations, and the ability to take bicycles onto rail vehicles during peak periods.

Automobile access should consider the capacity of park-and-ride or transit station parking lots relative to demand and the pedestrian environment within parking lots and between lots and the transit stop. For transit systems that use a zone-based fare system, consideration should be given to the parking requirements of transit stops near a zone boundary where a drop in fare occurs, because passengers often drive to the first stop or station past the zone boundary to take advantage of the lower fare.

Passenger Loads

Although passenger loads are generally more of a comfort and convenience factor than a transit availability factor, when a transit vehicle is full when it arrives at a stop, passengers waiting at the stop cannot board and transit service is not available to those passengers at that time. Transit vehicle scheduling should provide sufficient frequency along routes to accommodate peak passenger demand volumes without having to pass up waiting passengers. Special consideration should be given to providing sufficient transit vehicles to locations with strong peaking characteristics (such as airports, sports stadiums, or concert venues), when many people will wish to board transit vehicles at the same time. Unusual weather conditions, such as snow and ice in some areas, can cause people who normally drive to use transit instead, resulting in overcrowded conditions. However, these conditions are difficult to try to plan for.

AVAILABILITY--ROUTE SEGMENTS

Hours of Service

Hours of service, also known as "service span," are simply the number of hours during the day when transit service is provided along a route, a segment of a route, or between locations. It is as important as frequency and service coverage in determining the availability of transit service to potential users: if transit service is not provided at the time of day a potential passenger needs to take a trip, it does not matter where or how often transit service is provided the rest of the day.

Hours of service LOS (see Table 11) is measured similarly for fixed-route and paratransit services. For fixed-route service, LOS is based on the number of hours per day when transit service is provided at least once an hour (corresponding to a minimum LOS E for service frequency and compatible with a typical 1-h analysis period). For paratransit service, LOS is based on the number of hours per day when service is offered. As with frequency, hours of service LOS can vary by day: weekdays a route may operate at LOS B, Saturdays at LOS D, and Sundays at LOS F. Hours of service LOS is intended only for transit service provided within cities; intercity service should use only the frequency LOS measure, which is based on the number of trips provided per day.

TABLE 11 Hours of service LOS

LOS	Hours per Day	Comments
A	19-24	Night or owl service provided
B	17-18	Late evening service provided
C	14-16	Early evening service provided
D	12-13	Daytime service provided
E	4-11	Peak hour service/limited midday service
F	0-3	Very limited or no service

Fixed route: number of hours per day when service is provided at least once an hour
Paratransit: number of hours per day when service is offered

At LOS A, service is available for most or all of the day. Workers who do not work traditional 8 am to 5 PM jobs receive service and all riders are assured that they will not be stranded until the next morning if a late-evening transit vehicle is missed. At LOS B, service is available late into the evening, which allows a range of trip purposes other than commute trips to be served. Transit runs only into the early evening at LOS C levels, but still provides some flexibility in one's choice of time for the return trip home. Service at LOS D levels meets the needs of commuters who do not need to stay late and still provides service during the middle of the day for others. At LOS E, midday service is limited or non-existent and commuters have a limited choice of travel times. Finally, at LOS F, transit service is offered only a few hours a day or not at all.

Other Measures

The same accessibility considerations that apply to transit stops also apply to route segments. A potential measure of pedestrian, bicycle, and ADA accessibility for a route segment could include the percentage of transit stops along the segment that meet certain accessibility criteria. Automobile access should also consider the frequency of park-and-ride lots along a route, to minimize the number of vehicle miles traveled on the area's roadway system by motorists traveling to transit.

AVAILABILITY--SYSTEM

Service Coverage

Service coverage is a measure of the area within walking distance of transit service. As with the other availability measures, it does not provide a complete picture of transit availability by itself, but when combined with frequency and hours of service, it helps identify the number of opportunities people have to access transit from different locations. Service coverage is solely a system measure: at the route segment or transit stop level, if transit service is provided, coverage exists in that area or at that location.

One measure of service coverage is route kilometers per square kilometer (or route miles per square mile). This measure is relatively easy to calculate, but does not address systemwide how well the areas that generate the most transit trips are being served, nor does it address how well transit service is distributed across a given area.

Another measure would be the percentage of the system area served. However, land uses and population and job densities may vary greatly from one system to another, depending on how land uses have developed and how the system's boundaries have been drawn. Urban transit system boundaries might include large tracts of undeveloped land that may develop in the future, while countywide systems will likely include large tracts of rural land. Neither area would be expected to generate transit trips. How the boundaries are drawn will determine how much area is included within the service area, which in turn will affect any area-based performance measures. As a result, service areas are not the best basis for developing service coverage performance measures.

The actual area covered by transit will be smaller than a transit system's service area, depending on land use patterns in the area and a system's financial abilities to provide service. Transit routes are not run to areas where there are no passengers to serve, even though those areas might lie within the transit agency's service area. (However, routes might be run through undeveloped areas to connect two developed areas.)

By itself, the service coverage area is not the best performance measure, because it does not lend itself easily to comparisons of systems and because it does not address how well the areas that can support transit service (by having sufficient population and/or employment density) are served.

To equalize comparisons of systems and to assess how well a transit system serves the areas most likely to produce transit trips, service coverage LOS uses the concept of a *transit-supportive area.* The transit-supportive area is the portion of a transit agency's service area that provides sufficient population or employment density (or an equivalent mix) to require service at least once per hour.

Service coverage LOS is based on the percentage of the transit-supportive area covered. Table 12 presents the ranges of service coverage LOS.

Service coverage is an all-or-nothing issue for transit riders--either service is available for a particular trip or it is

TABLE 12 Service coverage LOS

LOS	% Transit-Supportive Area Covered
A	90.0-100.0
B	80.0-89.9
C	70.0-79.9
D	60.0-69.9
E	50.0-59.9
F	<50.0

Transit-Supportive Area: The portion of the area being analyzed that has a household density of at least 7 5 units per gross hectare (3 units per gross acre) or an employment density of at least 10 jobs per gross hectare (4 jobs per gross acre) **Covered Area:** The area within 0.4 km (0 25 mi) of local bus service or 0 8 km (05 mi) of a busway or rail station, where pedestrian connections to transit are available from the surrounding area

not. As a result, there is no direct correlation between service coverage LOS and what a passenger would experience for a given trip. Rather, service coverage LOS reflects the number of potential trip origins and destinations available to potential passengers. At LOS A, 90 percent or more of the transit-supportive area has transit service.

MEASURES OF QUALITY--TRANSIT STOPS

Passenger Loads

From the passenger's perspective, passenger loads reflect the comfort level of the on-board vehicle portion of a transit trip--both in terms of being able to find a seat and in overall crowding levels within the vehicle. From a transit operator's perspective, a poor LOS may indicate the need to increase service frequency or vehicle size in order to reduce crowding and to provide a more comfortable ride for passengers.

Passenger load LOS for bus and rail uses the same mea*sure--area per passenger--but* the ranges used to determine LOS differ between the two modes because of differences in the level of crowding that passengers will tolerate and because most rail modes (with the notable exception of commuter rail) provide more standing area than do buses. Passenger load LOS can be measured by time of day (e.g., LOS D peak, LOS B off-peak) or by the amount of time a certain condition occurs (e.g., some passengers must stand for up to 10 min). The *load factors* (passengers per seat) given in Table 13 can be used to estimate level of service.

At LOS A load levels, passengers can spread out and use empty seats to store parcels and bags, rather than carry them on their laps. At LOS B, some passengers will have to sit next to others, but others will not. All passengers can still sit at LOS C, although the choice of seats will be very limited. Some passengers will be required to stand at LOS D load levels, while at LOS E, a transit vehicle will be as full as passengers will normally tolerate. LOS F represents crush loading levels. A greater range of areas per passenger is

TABLE 13 Passenger Load LOS

	Bus		Rail		
LOS	**M^2/p**	***p/seat****	**m^2/p**	***p/seat****	**Comments**
A	>1.20	*0.00-0.50*	>1.85	*0.00-0.50*	No passenger need sit next to another
B	0.80-1.19	*0.51-0.75*	1.30-1.85	*0.51-0.75*	Passengers can choose where to sit
C	0.60-0.79	*0.76-1.00*	0.95-1.29	*0.76-1.00*	All passengers can sit
D	0.50-0.59	*1.01-1.25*	0.50-0.94	*1.01-2.00*	Comfortable standee load for design
E	0.40-0.49	*1.26-1.50*	0.30-0.49	*2.01-3.00*	Maximum schedule load
F	<0.40	*>1.50*	<0.30	*>3.00*	Crush loads

*Approximate values for comparison LOS is based on area per passenger.

	Bus		Rail		
LOS	**Ft^2/p**	***p/seat****	**ft^2/p**	***p/seat****	**Comments**
A	>12.9	*0.00-0.50*	>19.9	*0.00-0.50*	No passenger need sit next to another
B	8.6-12.9	*0.51-0.75*	14.0-19.9	*0.51-0.75*	Passengers can choose where to sit
C	6.5-8.5	*0.76-1.00*	10.2-13.9	*0.76-1.00*	All passengers can sit
D	5.4-6.4	*1.01-1.25*	5.4-10.1	*1.01-2.00*	Comfortable standee load for design
E	4.3-5.3	*1.26-1.50*	3.2-5.3	*2.01-3.00*	Maximum schedule load
F	<4.3	*>1.50*	<3.2	*>3.00*	Crush loads

*Approximate values for comparison. LOS is based on area per passenger.

provided for rail LOS than for bus LOS, as rail tends to provide fewer seats in favor of more standing room.

Other Measures

Reliability

Reliability is discussed as a service measure in the next section, route segments, because it tends not to vary between adjacent stops.

Amenities

The kinds of amenities provided at transit stops are usually a matter of agency policy, based on the number of boarding riders that would benefit from a particular amenity, as well other factors. Table 14 lists common transit amenities, typical ranges of boarding passengers used by transit systems to warrant their installation, and other factors to be considered when considering these amenities.

MEASURES OF QUALITY--ROUTE SEGMENTS

Reliability

Several different measures of reliability are used by transit systems. The most common of these are as follows:

- On-time performance,
- Headway adherence (the consistency or "evenness" of the interval between transit vehicles),
- Missed trips, and
- Distance traveled between mechanical breakdowns.

On-time performance, the most widely used measure in the transit industry, is a measure that users can relate to and encompasses several of the factors listed above that influence transit reliability. However, when vehicles run at frequent intervals, *headway adherence* becomes important to passengers, especially when vehicles arrive in bunches, causing overcrowding on the lead vehicle and longer waits than expected for the vehicles.

Most transit systems define a fixed-route transit vehicle as "late" when it is more than 5 min behind schedule. Some systems consider transit vehicles to be on time when they depart 1 to 3 min early, but most systems consider an early departure as not being on time. From the perspective of a passenger waiting for a transit vehicle, an early departure is often equivalent to a vehicle being late by the amount of one headway. Reliability LOS considers "on-time" for fixed-route service to be a departure from a published timepoint 0 to 5 min after the scheduled time or an arrival at the end of the route no more than 5 min after the scheduled time. Early departures are not considered "on-time." Reliability data routinely collected by field supervisors may not be the best to use for determining on-time performance, as when a problem occurs that delays vehicles. In such a situation, the supervisor generally will be working to fix the problem, rather than continuing to collect data. As a result, the data may not include all late transit vehicles.

In the case of deviated fixed-route service, with a bus traveling to the rider, rather than the rider traveling to meet a bus, early arrivals and departures are not as critical. Also, maintaining a consistent schedule from day to day is harder. Therefore, reliability LOS considers "on-time" for deviated

TABLE 14 Typical transit stop amenities

Amenity	Typical Daily Boarding Volumes at Stop	Other Factors to Consider
Shelter	10 (rural) 25 (suburban) 50-100 (urban)	Number of transfers at a stop Available space to place shelter ADA requirements Availability of alternative shelter Average passenger waiting time
Bench	Somewhat lower than shelter threshold	Insufficient space for shelter Walls, stairs, etc. that attract passengers onto adjacent property Stops used by elderly/disabled
Landing Pad	--	Wheelchair deployments at stop Muddy waiting areas Waiting areas damaging adjacent property
Information Signs	100	Major trip generators & transfer points Number of routes using a stop Room to install display
Trash Receptacles	--	Evidence of litter problem at a stop Availability of sponsor for maintenance Room to install adjacent to the bus stop

fixed-route service to be a pickup within 10 min of the scheduled time.

The only paratransit on-time performance measure identified in the literature was that used by the Port Authority in Pittsburgh, Pennsylvania, which defines a pickup within 20 min of the scheduled time as "on-time"; this is the criterion used for reliability LOS for paratransit.

Table 15 presents reliability LOS grades for transit service operating with frequencies greater than 10 min. The LOS thresholds are based on the systemwide on-time performance reported by 83 transit properties; the comments provided in the table reflect a passenger's perspective of the various LOS grades, based on five round trips per week with no transfers.

At LOS A, passengers experience highly reliable service and are assured of arriving at their destination at the scheduled time except under highly unusual circumstances. Service is still very reliable at LOS B, but one transit vehicle a week will be late on average if a passenger must transfer. At LOS C, at least one ride a week will be late on average, more if transfers are involved. At LOS D and E, one becomes less and less assured of arriving at the scheduled time and one may choose to take an earlier trip to ensure not being late. At LOS F, the number of late trips is very noticeable to passengers.

Other Measures

Travel Speed

Travel speed is a useful route segment performance measure because it reflects how long a trip may take, without depending on the length of a route segment. Transit priority measures, improvements to fare collection procedures, use of low-floor buses, and other similar actions implemented along a route segment will be reflected as improvements in travel speed.

Transit/Auto Travel Time

The transit auto/travel time measure introduced in the next section can also be used to evaluate the level of service of individual trips (for example, from a suburb to the CBD or between suburbs).

MEASURES OF QUALITY--SYSTEM

An important factor in a potential transit user's decision to use transit regularly is how much longer the trip will take compared with the automobile. Although some transit operators emphasize the "additional free time" aspect of riding transit in their promotional materials--to read, relax, catch up on extra work, etc.--without having to deal with the disadvantages of rush-hour driving, most people still prefer to drive their own cars unless high out-of-pocket costs (such as parking charges) provide a disincentive or unless transit travel time is competitive with the automobile.

The level of service measure is the *door-to-door difference between automobile and transit travel times,* including walking, waiting, and transfer times (if applicable) for both modes. It is a measure of how much longer (or in some cases, shorter) a trip will take by transit. The trip length is not as important as the trip time--a 20-mi trip that takes an hour longer by transit and a 5-mi trip that takes an hour longer both require an extra hour out of one's day--although longer trips have a greater potential for taking longer.

Travel time for transit includes walk time from one's origin to transit (assumed to be an average of 3 min), wait time (5 min), travel time on-board transit (varies), walk time from transit to one's destination (3 min), and any transfer time required (varies). Travel time for automobiles includes travel time in the automobile and time required to park one's car and walk to one's destination (assumed to be an average of 3 min). Walk time is based on a maximum 0.4-km (0.25 mi) walk to transit at 5 km/h (3 mph), which will take about 5 min; not all transit users walk the maximum distance.

TABLE 15 Reliability LOS: on-time performance

LOS	On-Time Percentage	Comments*
A	97.5-100.0%	1 late transit vehicle per month
B	95.0-97.4%	2 late transit vehicles per month
C	90.0-94.9%	1 late transit vehicle per week
D	85.0-89.9%	
E	80.0-84.9%	1 late transit vehicle per direction per week
F	<80.0%	

Applies to routes with headways greater than 10 min
*user perspective, based on 5 round trips/week of their travel on a particular transit route with no transfers

"On-time" = 0-5 min late departing published timepoint (fixed route)
arrival within 10 min of scheduled pick-up time (deviated fixed route)
arrival within 20 min of scheduled pick-up time (paratransit)

TABLE 16 Transit/Auto Travel Time LOS

LOS	Travel Time Difference (min)	Comments
A	≤0	Faster by transit than by automobile
B	1-15	About as fast by transit as by automobile
C	16-30	Tolerable for choice riders
D	31-45	Round-trip at least an hour longer by transit
E	46-60	Tedious for all riders; may be best possible in small cities
F	>60	Unacceptable to most riders

Smaller cities may find it harder than large cities to achieve high levels of service for this measure. In the San Francisco Bay Area, for example, it is faster to travel between downtown Oakland and downtown San Francisco by BART during the a.m. rush hour than it is to drive alone over the Bay Bridge. On the other hand, for a city with a population under 50,000, where it is possible to drive virtually anywhere in the city in 10 to 15 min, the walk and wait time for transit by itself is nearly as much as the total automobile travel time, and the calculated LOS will suffer as a result. In general, for small cities or for short trips, the total transit travel time will generally be significantly longer than the automobile travel time.

Because transit/auto travel time is a system measure, its data requirements are greater than those for transit stop and route segment measures. This section presents two methods for calculating transit/auto travel time LOS: one using a transportation planning model, another by hand.

As with many of the other service measures, transit/ auto travel time can be measured at different times of the day, for example, at peak and off-peak times. Because peak hour traffic congestion tends to lengthen automobile trip times, the calculated LOS will often be *better* during peak hours than during the rest of the day (see Table 16).

Door-to-door travel by transit is faster than by auto at LOS A. This level of service provides considerable incentive to potential riders to use transit. At LOS B, the in-vehicle travel times by auto and transit are comparable, but the walk and wait time for transit makes the total trip by transit slightly longer. Riders must spend an extra hour a day using transit at LOS C levels and up to 1_ hours at LOS D. At LOS E, individual trips take up to an hour longer by transit than by automobile; however, this may be the best possible performance in small cities where automobile travel times are low. Service at LOS F levels involve travel times so long as to be unacceptable to most riders.

SECTION 6

CONCLUSIONS

The complete TCQSM contains equations, graphs, photographs, and sample problems to aid practitioners in designing and operating transit facilities. It also contains a thorough glossary of terms used in the manual. This digest does not replace the full manual, but only illustrates the basic principles more fully developed in the TCQSM.

The TCQSM: First Edition, is intended to be a document that will develop with use. Periodically, new editions will be released that will incorporate new material provided by researchers and transit practitioners.

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PROJECT PANEL A-15

MICHAEL S. TOWNES, *Peninsula Transportation District Commission* (Chair)
TARA BARTEE, *Florida DOT*
ALFRED H. HARF, *Potomac and Rappahannock Transportation Commission*
WOLFGANG S. HOMBURGER, *Consultant*
HERBERT S. LEVINSON, *Herbert S. Levinson Transportation Consultants*
FRANKLIN L. SPIELBERG, *SG Associates, Inc.*
STAN TEPLY, *University of Alberta*
JOSEPH GOODMAN, *FTA Liaison Representative*
RICHARD A. CUNARD, *TRB Liaison Representative*