CHAPTER 4
QUALITY OF SERVICE CONCEPTS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

Quality of service reflects the passenger's perception of transit performance.

Quality of service reflects the passenger's perception of transit performance. The performance measures used to describe this perception are different from the financial and output-focused performance measures typically reported by transit agencies to the National Transit Database (*1*) and from the automobile operations performance measures that are a major focus of the *Highway Capacity Manual* (*2*). Quality of service depends to a great extent on the operating decisions made by a transit agency within the constraints of its budget, particularly decisions on where transit service should be provided, how often and how long it is provided, and how it is provided.

Ultimately, quality of service reflects how well transit service meets the needs of its customers, which has ridership implications. However, a balance must be struck between the quality of service that passengers ideally would like and the quality of service that a transit agency (*a*) can afford to provide or (*b*) would reasonably provide, given a base demand for transit service. Better quality of service is more attractive to potential passengers and generates higher ridership than lower quality of service, but better quality of service often (but not always) also entails higher costs.

Chapter Organization

Organization of Chapter 4.

Chapter 4 of the *Transit Capacity and Quality of Service Manual* (TCQSM) explores the basic concepts of quality of service:

- The remainder of Section 1 discusses the roles of transit in North America and the different perspectives that different stakeholders provide when assessing the performance of transit service.
- Section 2 presents findings from research on the most important quality of service factors from the passenger perspective.
- Section 3 organizes these quality of service factors into a framework that includes (*a*) measures of *transit availability* that determine whether or not transit is an option for a given trip, and (*b*) measures of *transit comfort and convenience* that influence a potential customer's decision to use transit, for trips where transit is an available option.
- Section 4 presents the ridership and cost implications of making changes in quality of service.
- Section 5 is a list of the references that provided material used in the chapter.
- Appendix A provides metric versions of exhibits presented in U.S. customary units only within the chapter.

How to Use This Chapter

The remainder of Section 1 will be of greatest interest to those readers new to the transit industry, although the material on transit performance measurement needing to consider a variety of stakeholder perspectives will also be useful to transit agency managers, decision makers, and staff involved with measuring agency performance.

Section 2 provides reference information not needed to apply the TCQSM's methods but which nevertheless have some bearing on them. The material on customer satisfaction research is provided for those readers wanting additional support for the TCQSM's selection of service measures. The material on value of time provides the relative values that passengers place on different aspects of their transit trip; it is hoped that this material can be expanded in future editions of the manual to provide even more quantitative information about passengers' perspectives on quality of service.

Section 3 will be valuable for many readers. The section can be read by all users who intend to apply the quality of service methods found in Chapter 5, as the section presents the manual's framework for measuring quality of service. For other readers, this section describes the major factors that influence quality of service and their importance.

Finally, Section 4 will be useful for transit agencies wishing to evaluate the potential effects of making changes to quality of service, both in terms of ridership and in terms of operating and capital costs.

Other Resources

Other TCQSM material related to this chapter includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 5, Quality of Service Methods, which presents methods for evaluating the quality of service measures introduced in this chapter; and
- The manual's CD-ROM, which provides links to electronic versions of all of the TCRP reports referenced in this chapter.

ROLES OF TRANSIT

Transit plays two major roles in North America. The first role is to accommodate passengers who choose to use transit for their trip making even though they have other means of travel available to them, most likely a motor vehicle. The other role is to provide basic mobility for those unable to drive.

Choice Riders

Passengers who have more than one travel option available to them are often referred to as *choice* riders. These customers may choose transit for a given trip for a variety of reasons, including:

Choice riders choose to use transit even though other means of travel are available.

- Saving money (e.g., parking costs, fuel costs, tolls, insurance and registration costs associated with owning a car or multiple cars);
- Having the potential for a faster or more reliable trip compared to competing modes, particularly in large metropolitan areas and where natural barriers constrain the roadway network;
- Avoiding the need to drive in congested roadway conditions;
- Being able to use travel time more effectively (e.g., reading, working); and
- Helping the environment by not contributing to the negative impacts of automobile travel.

Choice riders use transit particularly during peak periods for work trips. In this role, transit is essential for mobility in the downtowns of some major cities— which could not survive without the existence of transit service—and in other concentrated employment centers. However, this peaked ridership demand also means that more vehicles and operators are needed to serve peak-period demand than off-peak demand. Peak-period transit demand is often highly directional—toward major employment centers in the morning and away in the afternoon—with unused capacity available in the off-peak direction. The more that ridership can also be attracted to the off-peak direction—for example, through the design of the transit route (e.g., having strong trip attractors, or *anchors,* at both ends of the route) or through fare incentives—the more productive the route will be, and the more cost effective it will be to provide a high quality of service.

Transit-dependent Riders

Transit-dependent riders rely on transit to meet basic mobility needs.

Transit also provides basic mobility for those segments of the population too young, too old, or otherwise unable to drive due to physical, mental, or financial disadvantages. In 2009, about 31% of the population in both the United States (*3*) and Canada (*4*) did not possess a driver's license. This portion of the population therefore depended on others to transport them (e.g., in autos, in taxis, or on transit), made trips by walking or bicycling, or used a combination of these. Such transit users have been called *captive* or *transit-dependent* riders. Transporting these riders is the principal role for those transit services provided specifically for persons with disabilities and is the dominant role in many smaller transit systems.

Role of Quality of Service in Attracting and Retaining Ridership

Although transit may be the best or only travel choice available at a given time for many types of trips made by transit-dependent riders, quality of service is still an important consideration for both riders and service providers. For riders, a poor quality of service can limit the options available for finding and holding a job, taking classes, or taking care of basic living needs. For transit providers, providing a good quality of service can help retain riders once they are no longer transit dependent.

In the major cities in North America, transit serves higher numbers of both choice and captive riders. The variation in transit mode share among urban areas reflects differences in population, downtown employment and parking costs, extent of bus and rail transit service, and geographic characteristics.

Transit trips can be both time and cost competitive to the auto under certain operating conditions, particularly where exclusive right-of-way operation, on-street transit lanes, or other forms of transit priority that provide significant time savings can be provided. Time or cost savings helps attract ridership from single-occupant vehicles, thereby reducing traffic congestion and improving air quality.

Importance of good pedestrian and bicycle connections to transit.

Transit passengers must of necessity be pedestrians or bicyclists at one, or usually, both ends of their trips. It is therefore important that the land uses along transit routes and around transit stations help support transit service by providing safe and direct linkages between transit stops and passengers' origins and destinations. Providing these linkages also helps develop a more walking- and bicycling-friendly environment that encourages the use of these modes for other trips, thereby creating a more active, and potentially more secure environment around transit stops. Providing transit-supportive land uses around transit stops and stations also helps take full advantage of the quality of service provided at that location and can generate the ridership that supports even better quality of service.

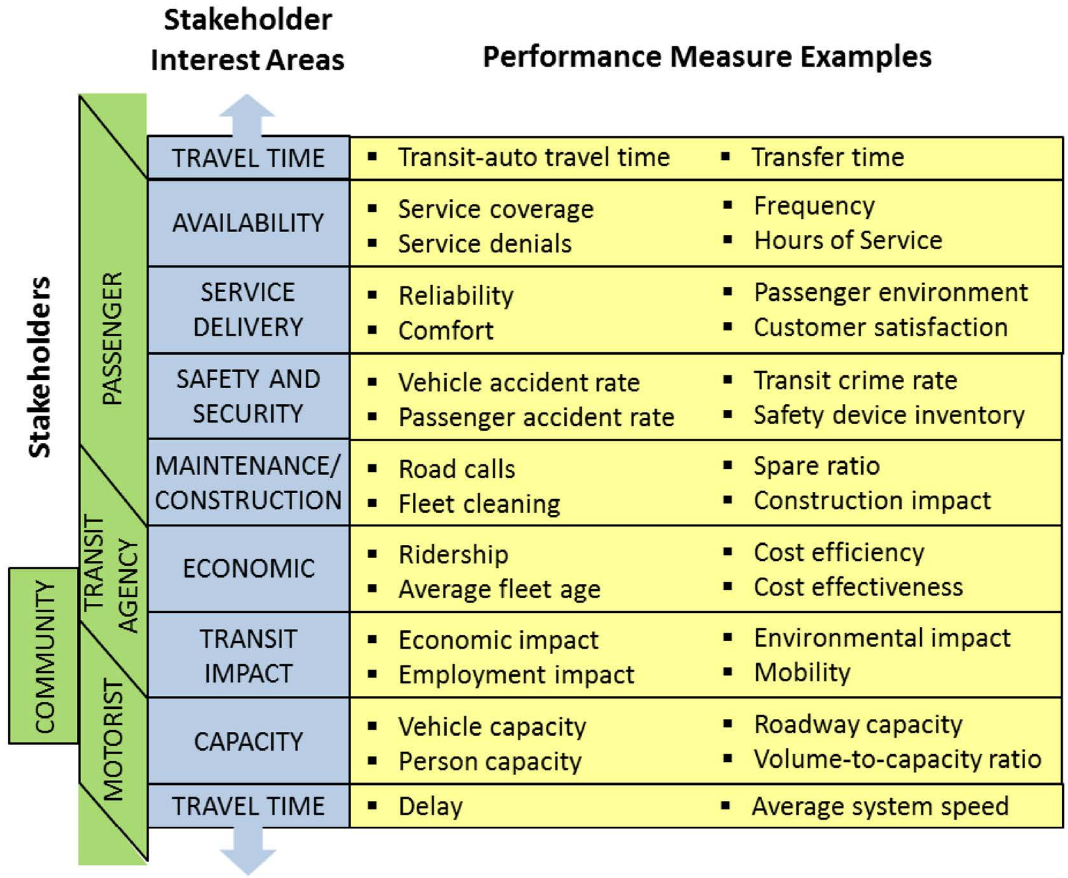
PERFORMANCE POINTS OF VIEW

As the previous discussion suggested, transit service directly or indirectly affects many aspects of a community. As a result, there are a number of different stakeholders who are interested in transit performance. These stakeholders include:

- *Transit passengers,* who have to decide which travel mode to use (when they have a choice of modes), or whose travel options may be constrained by the quality of the service (when they do not have a choice);
- *Transit agency staff and decision makers,* who have to make choices about how to allocate a finite amount of resources to best meet the agency's goals and objectives, and who also have to report on transit performance to other agencies providing funding support;
- *Motorists,* who interact with transit vehicles on the road and who may benefit when other motorists decide to use transit, and *roadway agency staff and decision makers,* who have their own sets of stakeholders, goals, and objectives, and need to become partners in order to implement roadway infrastructure improvements that can benefit transit; and
- *Community members and decision makers,* who may directly support transit service through taxes and who may indirectly benefit from the role that transit plays in the community (e.g., congestion relief, air quality, mobility, source of employment).

Each of these major stakeholder groups has its own sets of interests and priorities—a point of view. Some of these points of view overlap with those of other stakeholders and others are a primary focus of one set of stakeholders. Consequently, transit performance needs to be addressed in a way that addresses the points-of-view of multiple stakeholders. Exhibit 4-1 shows some of the primary interest areas of major stakeholder groups, along with potential performance measures for those interests.

Exhibit 4-1
Transit Performance Stakeholders, Interest Areas, and Performance Measure Examples



Source: Derived from *TCRP Report 88* (*5*).

Transit performance measures can reflect passenger, transit agency, motorist, and community points of view.

Travel time overlaps the motorist and passenger points of view.

Transit Agency

The transit agency point of view reflects transit performance from the perspective of the transit agency as a business. Although transit agencies are naturally concerned with all aspects of transit service provision, the categories listed under the transit agency point-of-view—particularly economic performance and maintenance and construction—are ones of greater interest to transit agencies than to the other stakeholders. Performance measures in these categories are also ones most likely to be tracked by transit agencies.

One reason that transit agency–oriented measures are more commonly tracked than others is that this category includes most of the measures routinely collected in the United States for the Federal Transit Administration's National Transit Database (NTD, *1*). Most NTD measures relate to cost and utilization. These measures are important to the transit agency—and indirectly to passengers—by reflecting the amount of service a transit agency can afford to provide on a route or the system as a whole. The utilization measures (e.g., ridership) indirectly measure passenger satisfaction with the quality of service provided. However, with a few exceptions related to safety and service availability (e.g., vehicle revenue hours per directional mile and vehicles operated in maximum service per directional mile), the NTD measures do not directly reflect the passenger point of view.

Motorist

The motorist point of view includes measures of vehicular speed and delay, such as those routinely calculated for streets and highways using the *Highway Capacity Manual* (*2*). This point of view also includes measures of roadway capacity in terms of the numbers of transit vehicles or total vehicles that can be accommodated. Because transit vehicles carry passengers, these measures also indirectly reflect the passenger point of view: passengers on board a transit vehicle traveling at an average speed of 12 mi/h (20 km/h) individually experience the same average travel speed as the vehicle. However, because these vehicle-oriented measures do not take passenger loading into account, the passenger point of view is hidden, as all vehicles are treated equally, regardless of the number of passengers in each vehicle. For example, while a single-occupant vehicle and a 40-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 40 times as great.

Community

The community point of view measures transit's role in meeting broad community objectives. Measures in this area include measures of the *impact* of transit service on different aspects of a community, such as employment, property values, or economic growth. This viewpoint also includes measures of how transit contributes to community *mobility* and measures of transit's effect on the *environment.* Many of these measures reflect things that are important to passengers, but which may not be directly perceived by passengers or by others on an individual trip basis.

Passenger

Quality of service focuses on those aspects of transit service that directly influence how passengers perceive the quality of a particular transit trip. It is defined as follows:

Quality of service focuses on the passenger point of view.

> The overall measured or perceived performance of transit service from the passenger's point of view.

In contrast to transit capacity, where issues are mainly concentrated in larger cities, transit quality of service matters to communities of all sizes. The factors that influence quality of service are introduced in the next section.

2. QUALITY OF SERVICE FACTORS

Two important ways of identifying the quality of service factors that are most important to existing and potential passengers are (*a*) to ask them directly through customer satisfaction surveys and (*b*) to observe how they react when given actual or hypothetical choices between transit services or travel modes with different characteristics. This section explores how these techniques have been used to identify the factors most important to passengers.

CUSTOMER SATISFACTION RESEARCH

Several large-scale customer satisfaction studies appear in the literature that help identify quality of service factors important to passengers.

TCRP Project B-11, "Customer-Defined Service Quality"

This TCRP project developed guidance for transit agencies on conducting customer satisfaction surveys to allow agencies to identify the most important customer-service issues that affect, or could potentially affect, their system. The project's surveying techniques were pilot tested at three transit agencies—an urban rail system, a suburban bus system, and a small city bus system—and more than 13,000 surveys were distributed, with response rates of 33 to 46 percent. These surveys asked passengers to rate 46 transit system attributes on a scale of 1 to 10 and to identify whether they had experience a problem with that attribute within the last 30 days (*6*).

For ease of comparison, the 46 surveyed attributes can be grouped into the following nine categories: comfort, nuisances, scheduling, fares, cleanliness, in-person information, passive information, safety, and transfers. Attributes relating to scheduling were the top area of existing concern, followed by comfort and nuisances (e.g., rowdy passengers). When potential problems (areas not currently a problem but still of concern to passengers) were analyzed, fares and scheduling were the top concerns, followed by comfort and safety. Nuisances was the category with the least potential for high levels of concern among passengers who had not experienced a problem in that area in the previous 30 days.

Florida Department of Transportation

The Florida Department of Transportation (FDOT) commissioned a survey of customer satisfaction factors for six larger Florida transit systems (*7*). As with the TCRP B-11 survey, the FDOT survey sought to identify both existing problems and potential problems. A total of more than 14,500 surveys were returned from the six systems, representing response rates of up to 28%. The surveys covered 22 factors, including hours of service, frequency of service, convenience of routes, on-time performance, travel time, transferring, cost, information availability, vehicle cleanliness, ride comfort, employee courtesy, perception of safety, bus stop locations, and overall satisfaction.

Existing problems of greatest significance to Florida customers were hours of service, routes, and headways. Potential problems of greatest significance were routes and headways, hours of service, bus ride comfort, printed schedules, and safety and cleanliness.

NCHRP Project 3-70, "Multimodal Level of Service for Urban Streets"

As part of the work to develop a transit level of service (LOS) measure for urban streets that could be directly compared to similar measures for the automobile, bicycle, and pedestrian modes, onboard surveys were conducted on bus routes with varying service characteristics (e.g., frequency, loading, reliability, amenity provision) operated by five different transit agencies around the U.S. Customers were asked to rate their overall satisfaction with their trip, along with their satisfaction about specific aspects of their trip (e.g., frequency, reliability) and—in the first phase of the survey effort—to select the service quality factors contributing most to their overall satisfaction, out of a list of 17 factors. More than 2,600 surveys were returned. In addition, as the starting and ending points of the customer's trip on the transit vehicle were known, customer responses could be compared to the conditions actually experienced (*8*).

Bus passengers' stated overall satisfaction varied greatly, even when making identical trips—so much so that no relationships could be drawn between overall satisfaction and various contributing factors to satisfaction. The researchers theorized that transit passengers surveyed on board are to some degree self-selected and that their trip must have already met some minimum threshold of satisfaction for them, otherwise they would not have been on board the transit vehicle. This threshold likely varies by individual, depending on the other travel choices available (*8*).

It was possible, however, to develop relationships between satisfaction with specific quality of service factors (e.g., frequency) and the conditions that surveyed passengers experienced. It was also possible to identify factors that passengers consistently stated as most contributing to their overall satisfaction. As shown in Exhibit 4-2, passengers consistently identified frequency as being the most important factor, while reliability, wait time (which relates to frequency and reliability), access (close to home and destination), and service span were also consistently stated as being contributors to passengers' satisfaction (*9*).

Exhibit 4-2
Factors Contributing Most to Stated Overall Satisfaction with a Transit Trip

	Route				
Rank	**A**	**B**	**C**	**D**	**E**
1	*frequency*	*frequency*	*frequency*	*frequency*	frequency
2	*wait time*	*reliability*	*close to home*	*reliability*	wait time
3	*reliability**	*wait time*	*reliability*	*close to home*	close to home
4	*close to home**	close to dest.	*wait time*	close to dest.	reliability
5	service span	close to home	close to dest.	wait time	service span
6	close to dest.	service span		service span	
7	friendly drivers				

Source: Dowling et al. (*9*).

Notes: *tie.
Italics indicate factors mentioned by 50% or more of surveyed passengers. Other listed factors were mentioned by at least 33% of surveyed passengers.
Dest. = destination.

VALUE OF TIME RESEARCH

The Value of Quality: Transit Planning Context

Ask most transit passengers how much their journey cost them and they will quote the price of their ticket. However, passengers also place a value on travel time and journey quality. Before making their ticket purchase decision, most passengers consider these issues and select an optimal travel option. In short, for each available travel option, they will subconsciously make a personal assessment of what is termed the *generalized cost* of their trip.

Transportation planners typically associate generalized costs with the requirements of strategic modeling and network assignment exercises—big picture studies into how people choose to get around cities and regions. However, such costs also incorporate transit's quality of service attributes, which affect choice of route and mode. Quality is represented both by the speed of the journey (including potential delays) and the quality of the facilities used during various stages of the journey. The higher the perceived cost of a combination of route and mode (e.g., longer travel time, more crowded conditions), the less likely a person would choose it for a given trip.

The econometric framework is underpinned by in-vehicle value of time (VoT). It provides the central reference point for the valuation of access, wait, and transfer travel time, and also for the valuation of non-time quality attributes; it is the glue that binds the framework together. Practitioners typically use generic and simplified values of time, often by neccessity (e.g., lack of available data or the need to model geographically large and diverse areas with relatively standardized parameters). However, values may vary by local context and quality improvements can alter them.

In-Vehicle Values of Time

Single point estimates for in-vehicle VoT (or value of travel time saved) are often quoted as a dollar-per-hour rate. These estimates reflect the average value placed on saving one hour of time within the relevant population. Exhibit 4-3 shows typical VoT values from the literature.

Exhibit 4-3
Typical Values of Time for Different Types of Travel

Type of Travel	VoT (% of Prevailing Wage Rate)
Personal travel	50%
Commercial (on the clock) travel	100% + benefits
Transit (in vehicle, seated)	25%-35%
Transit (in vehicle, standing)	50%
Transit (in vehicle, crowded)	100%
Waiting (unpleasant conditions)	Up to 175%

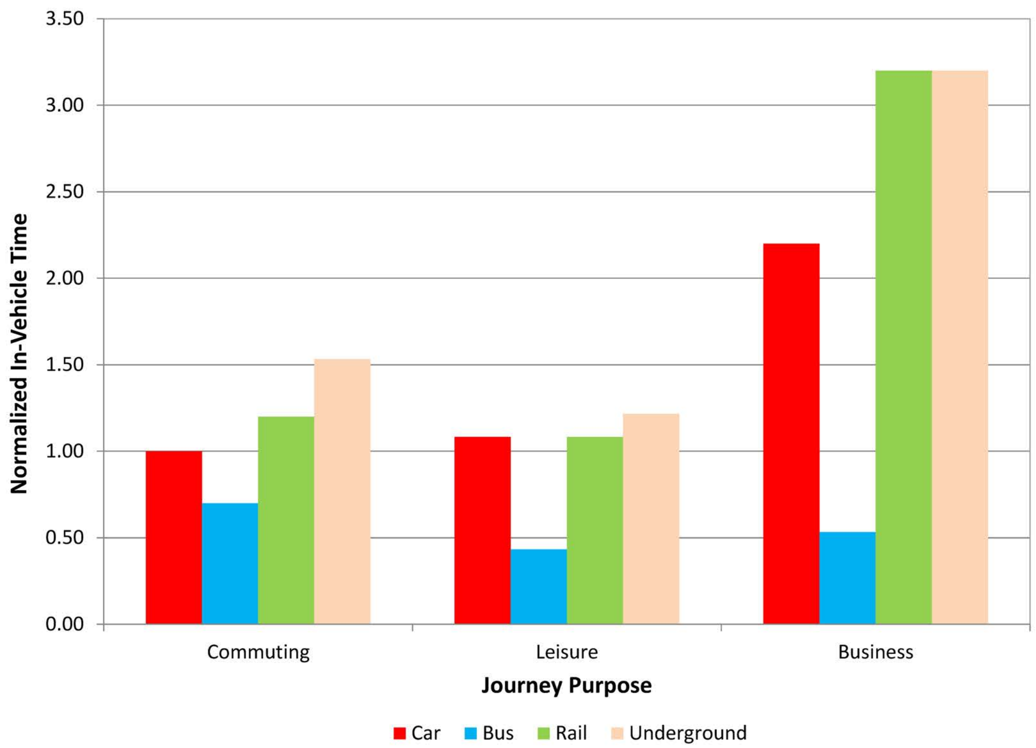
Source: Concas and Kolpakov (*10*).

The use of an average value or single-point estimate is by definition a simplification. The validity of using any such estimate will depend on the local circumstance, the context in which it is used, and the way in which the rate was calculated. For example, one source describes a range of British VoT ranging from £0.50 to £45.43 (*11*). The following subsections list some generally agreed reasons as to why VoT unit rates vary between sources.

Trip Purpose and Mode

As a general rule, modes that offer a higher speed or better quality of service attract passengers who value speed or quality more highly and are willing to pay a premium for those attributes. Trip purpose and mode of travel are key differentiators known to have an influence on in-vehicle VoT. Exhibit 4-4 shows the results of a review of over 200 British VoT studies (*12*), with values normalized to the commuting car driver valuation, which has been set to 1.0.

Exhibit 4-4
Relative Urban Travel Values of Time



Source: Derived from Wardman (*12*).

Exhibit 4-4 suggests that, for example, the average valuation for bus commuters is approximately half the average valuation for rail commuters—in other words, if the valuation for the average rail commuter was found to be $14/h, it could be inferred that the valuation for the average bus passenger may be in the region of $7/h. However, presenting summary data in this way can obscure some significant user type effects (*13, 14*). For example, although the average bus mode VoT is lower than the average rail mode VoT, individuals are likely to reveal a higher VoT when using bus because bus quality is generally perceived to be lower than rail quality.

Translating this to a real-world scenario, John Doe, who normally commutes by car to work, uses public transportation while his car is in the shop for repairs. His in-vehicle VoT when travelling by car is (hypothetically) $10/h, but because he perceives bus travel less positively, his in-vehicle VoT would be $15/h when travelling by bus. This means that only if John's bus journey time was two-thirds of his car journey time, would he perceive the in-vehicle portion of his bus and car options as being equivalent.

Trip Duration

Longer distance trips are generally agreed to attract a higher unit rate VoT. In other words, the longer the trip to be made, the more value the average passenger will place on reducing the travel time by a single unit of time. For example, the VoT values in Exhibit 4-4 were found to be higher for inter-urban travel by between 38% and 104% (*12*).

The American Association of State Highway and Transportation Officials (AASHTO) practice is to use non-linear, increasing unit rates for three time bands of 0–5 min, 5–15 min, and 15+ min. In the U.K., on the other hand, the normal practice is to apply VoT in fixed proportion to the average hourly rate, which is a pragmatic response to the reality of many transit preferential treatments, which deliver modest travel time savings, particularly when compared to projects designed to increase highway capacity (*15*).

One source (*16*) cites studies that indicate unit rate VoT increases for journeys above 40 min. Another source (*13*) describes a distance elasticity of 0.161 for in-vehicle transit time and 0.205 for in-vehicle auto time. These elasticities suggest that doubling the average trip duration will result in a VoT unit rate increase of between 16% and 20%.

Access, Transfer, and Wait Time

When compared to the in-vehicle component of a trip, the access, wait, and transfer elements typically require greater physical effort. Little or no productive use can be made of time during these stages of a trip and travelers may also encounter wayfinding difficulty and experience general anxiety associated with getting to a particular location on time. For these reasons, a unit of time spent during these stages of a transit trip is perceived as more onerous than a unit of in-vehicle time (*15*). This is a well-established principle. Exhibit 4-5 shows ranges of in-vehicle, walk, initial wait, and transfer time from eight U.S. studies from the 1960s to the 1990s reported in *TCRP Report 95* (*17*), along with a compilation of U.K. results, which suggest slightly lower average values (*12*).

Exhibit 4-5
Relative Values of Time for Different Stages of a Trip

	In-Vehicle Time	Walk Time	Initial Wait Time	Transfer Time
U.S. average	1.0	2.2	2.1	2.5
U.S. range	1.0	0.8–4.4	0.8–5.1[a]	1.1–4.4
U.K. average	1.0	1.7	1.8	N/A

Sources: *TCRP Report 95, Chapter 10* (*17*) and Wardman (*12*).
Note: N/A = not available. Values shown are multiples of the value of a unit of in-vehicle time.
(a) Two studies showed a sharp decrease in these values after the first 7–7.5 min of wait time.

In addition to these multipliers for in-vehicle time, some studies have identified transfer penalties in the range of 12–17 min of equivalent in-vehicle time. On the other hand, a bus re-restructuring in the Seattle area that moved from a relatively infrequent one-seat ride from suburbs to downtown Seattle to more-frequent service requiring a timed transfer at a transit center resulted in a 23% ridership gain over 2 years (*17*).

It can be seen from Exhibit 4-5 that there is considerable variability in reported VoT for a given stage of a transit trip. While some of this variability is the result of the type of study that generated the valuations (*12*), local context is also important and no universally applicable set of multiplier values exists.

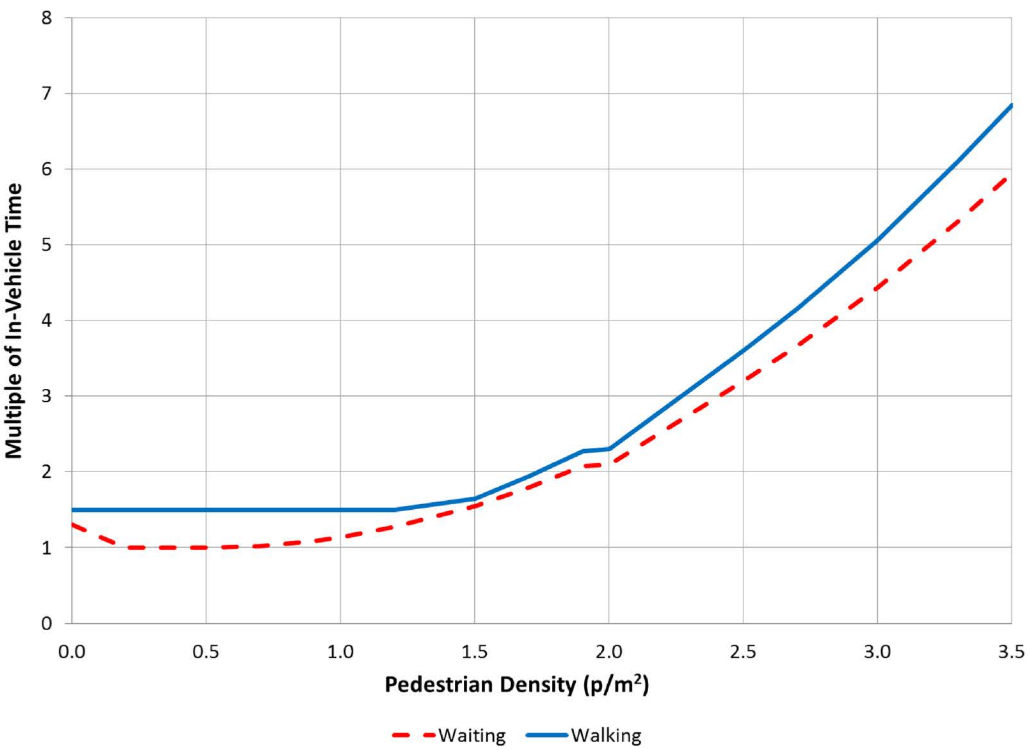
Value of Quality

In some cases, the influence of specific aspects of quality has such a significant influence on passenger perception that mechanisms have been developed for directly manipulating the journey stage multipliers to reflect differences in quality of service. In particular, crowding has a significant effect on the perception of time. Other quality attributes have a more marginal impact.

Platform Crowding Effects

Exhibit 4-6 shows a relationship developed in Australia between rail platform crowd density and perceived walk and wait times.

Exhibit 4-6
Relationship Between Platform Crowding and Perceived Walk and Wait Times

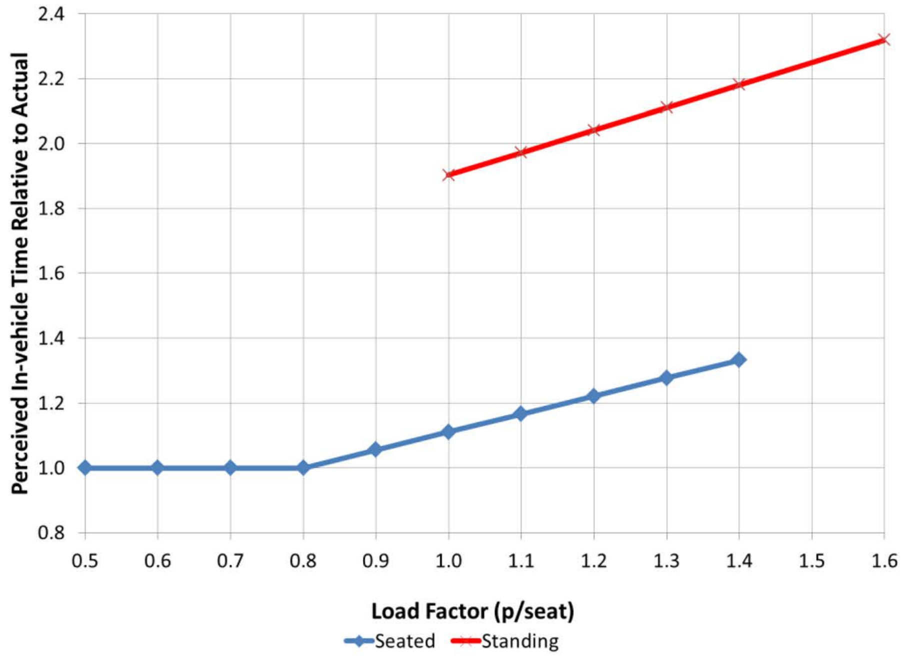


Source: Douglas Economics (*18*), quoted in Litman (*16*).
Note: 2 p/m^2 = 5.4 ft^2/p.

In-vehicle Crowding

Exhibit 4-7 shows British values of perceived in-vehicle time for seated and standing passengers in railcars.

Exhibit 4-7
Relationship Between Vehicle Crowding and Perceived Travel Time



Source: Derived from Balcombe (*11*).

Reliability

Unreliable transit service will increase average waiting time. If the impact on waiting passengers is measured in terms of *excess wait time* (the difference between the actual and scheduled departure time when a transit vehicle is late), the resulting time values may be converted to a monetary valuation of service unreliability. A value of 2 to 3 times the normal unit rate for *waiting* is typical (*19*); a study of public transport users in Auckland and Wellington, New Zealand found values of 3 to 5 times *in-vehicle* time (*20*).

Bus Stop Amenities

Exhibit 4-8 lists examples of the in-vehicle time equivalent of various types of amenities at a bus stop, derived from British data and converted from pence to equivalent values of time.

Exhibit 4-8
In-vehicle Time Equivalent of Bus Stop Amenities

Amenity	In-vehicle Time Equivalent (min)
Shelter with roof and end panel	1.3
Basic shelter	1.1
Lighting	0.7
Molded seats	0.8
Flip seats	0.5
Bench	0.2
Dirty bus stop	-2.8

Source: Derived from Balcombe (*11*).
Note: Positive VoT values in the exhibit indicate a benefit (i.e., a reduction in perceived time).

Real-time Arrival Information

Real-time information—whether provided through a display at a transit stop, by calling or texting an information service, or via a smartphone app—helps reassure passengers that their transit vehicle is on the way and can help them use their waiting time more efficiently:

- A study of a transit information tool in the Seattle area (available by calling, texting, smartphone app, or online) found that, on average, users with real-time information reported wait times that were 30% lower than users without it. In addition, the actual wait time was lower for users with real-time information because the information enabled those users to better plan their arrival at the bus stop (*21*).
- A study of real-time information at stops on a tram line in The Hague, Netherlands found that perceived wait time decreased 20% (1.3 min) (*22*).
- London Underground users overestimated their wait time with and without real-time information; however, the real-time information reduced the overestimation by an average of 0.7 min (*23*).
- Passengers were surveyed after countdown displays were installed at bus stops in London: 65% reported shorter wait times, although bus frequency did not change; 83% felt that time passed more quickly; and 89% agreed that waiting time was more acceptable with the information (*23*).

Other Aspects of Service

Monetary values (which can be converted into equivalent values of in-vehicle time) can be developed for many aspects of service quality—for example, driver friendliness and clarity of stop announcements. There are a number of examples of British research on these aspects of VoT, both published (e.g., *11–13*) and internal to transit operators.

3. QUALITY OF SERVICE FRAMEWORK

TRANSIT TRIP DECISION-MAKING PROCESS

Urban transport involves millions of individual travel decisions. Some are made infrequently—to take a job in a particular location, to locate a home outside an area with transit service, or to purchase a second car. Other decisions—when to make a trip or which mode to use—are made for every trip.

Availability

Is transit service available to a potential passenger?

A key decision is determining whether or not transit service is even an option for a particular trip. Transit service is only an option for a trip when:

- Service is available at or near the locations and times that one wants to travel, and one can access it (*spatial availability*);
- Service is provided at the times one desires to travel—often including the return trip (*temporal availability*);
- One knows how to use the service (*information availability*); and
- Sufficient space is available on transit vehicles and, potentially, at supporting facilities such as park-and-ride lots (*capacity availability*).

When service is not available, other aspects of service quality do not matter for a given trip.

If any one of these factors is not satisfied for a particular trip, transit will not be an option for that trip—either a different mode will be used, the trip will be taken at a less convenient time, or the trip will not be made at all. When service is not available at the times one wants to travel, other aspects of transit service quality will not matter to that passenger for that trip, as the trip will not be made by transit (or at all), regardless of how good the service is in other locations or at other times of the day or week. Exhibit 4-9 depicts these availability factors in the form of a flowchart.

Comfort and Convenience

If transit service is available, will a potential passenger find it comfortable and convenient?

If transit service is available as described above, then transit becomes an option for a given trip. At this point, passengers weigh the comfort and convenience of transit against competing modes. Some of the things that a potential passenger may consider include the following:

- Is the service reliable?
- How long is the wait? Is shelter available at the stop while waiting?
- Are there security concerns—walking, waiting, or riding?
- How comfortable is the trip? Will I have to stand? Are there an adequate number of securement spaces? Are the vehicles and transit facilities clean?
- How much will the trip cost?
- Is a transfer required?
- How long will the trip take in total? How long relative to other modes?

Unlike the first decision—whether or not transit is an option for the trip—the questions listed above are not necessarily pass/fail. People have their own personal values that they apply to a given question, and each person will weight their answers to these questions differently. Regular transit users familiar with the service may perceive transit service more favorably than non-users. In the end, the choice to use transit will depend on the availability of other modes and how the quality of transit service compares with that of competing modes. Exhibit 4-9 summarizes this decision-making process.

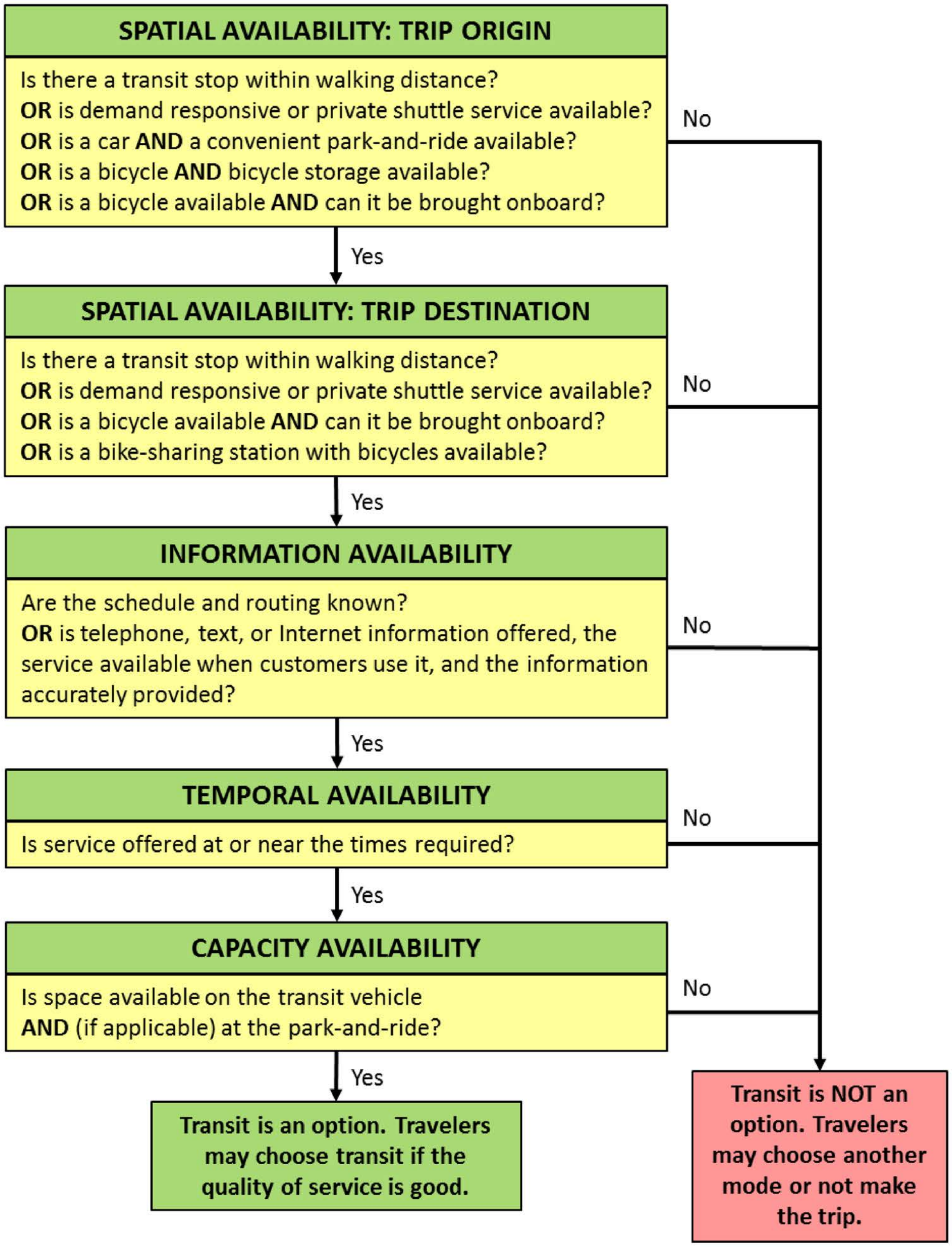


Exhibit 4-9
Transit Availability Factors

FRAMEWORK OUTLINE

Aspects of transit availability and transit comfort and convenience that are (*a*) important to passengers and (*b*) relatively easy to quantify and forecast are presented in the TCQSM in the form of *quality of service frameworks.* These frameworks—one for fixed-route service and one for demand-responsive service—focus on key performance measures that transit agencies can use to set service standards and to evaluate the quality of service they provide to their passengers.

Exhibit 4-10 presents the quality of service framework for fixed-route transit, while Exhibit 4-11 presents the framework for demand-responsive transit.

Exhibit 4-10
Quality of Service Framework: Fixed-Route Transit

Availability	Comfort and Convenience
Frequency	Passenger Load
Service Span	Reliability
Access	Travel Time

Exhibit 4-11
Quality of Service Framework: Demand-Responsive Transit

Availability	Comfort and Convenience
Response Time	Reliability
Service Span	Travel Time
Service Coverage	No-shows

Comparing the two exhibits, it can be seen that the two frameworks share a number of factors in common, but also have some differences specific to the type of service. As will be seen in Chapter 5, Quality of Service Methods, even where the frameworks do address similar factors, the performance measures used to evaluate fixed-route and demand-responsive service quality are almost always different.

Not every factor that affects quality of service can be included in the framework. For example, safety and security are areas that are important to passengers, but which are difficult to forecast. Therefore, it is important for analysts and decision makers not to lose sight of broader issues by focusing only on evaluating the factors that appear in the frameworks. The discussions in this chapter and the next help to highlight some of the other aspects of quality of service that may also be important to evaluate, depending on the needs of a given analysis.

The following sections describe the components of the quality of service frameworks in more detail.

TRANSIT AVAILABILITY

Spatial Availability

If transit service is located too far away from a potential passenger, transit use is not an option.

The presence or absence of transit service near one's origin and destination is a key factor in one's choice to use transit. Ideally, transit service will be provided within a reasonable walking distance of one's origin and destination. Alternatively, demand-responsive service will be available at one's doorstep for those unable to use fixed-route service. The presence of accessible transit stops, as well as accessible routes to transit stops, is a necessity for many persons with disabilities who wish to use fixed-route transit. Furthermore, upgrading existing facilities to meet Americans with Disabilities Act (ADA) requirements also results in a more comfortable walking environment for everyone. When transit service is not provided near one's origin, driving to a park-and-ride lot or riding a bicycle to transit service may be viable alternatives.

Service coverage considers both ends of a trip.

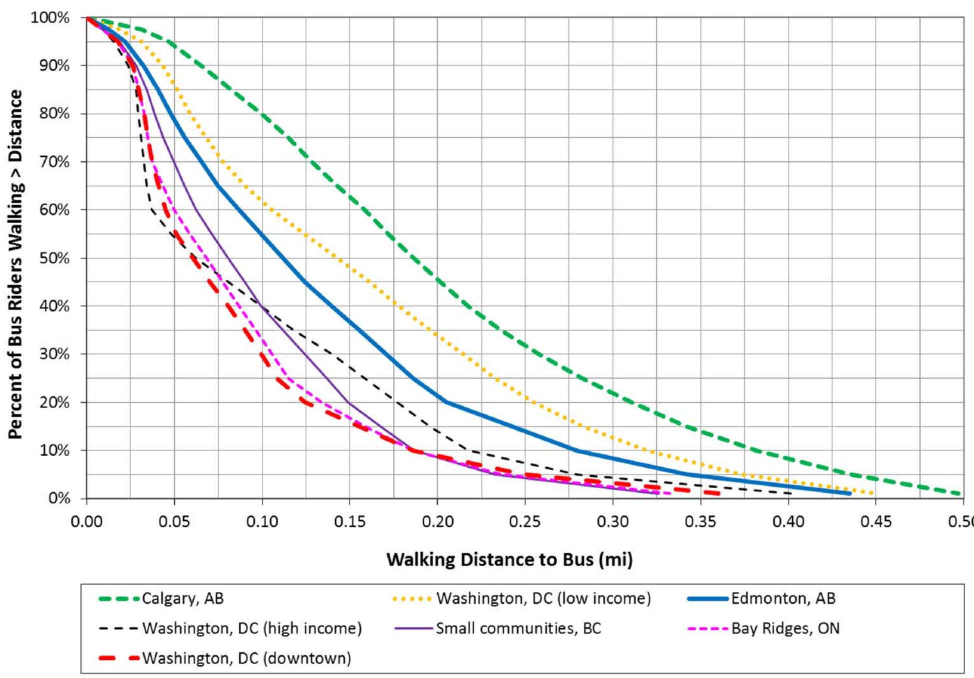
Service coverage considers both ends of a trip, for example, both home and work. Transit service at one's origin is of little use if service is not provided near one's destination. Options for getting from a transit stop to one's destination are more limited than the options for getting from one's origin to a transit stop. The car one drove to a park-and-ride lot will not be available at the destination, nor will a bicycle left behind in a storage facility. A bicycle carried on a bus-mounted bicycle rack or brought on board a train will be available at the destination, as long as space was available for the bicycle on the transit vehicle. In some cases, large employers may provide private shuttle service connecting transit stations to worksites.

Pedestrian Access

Walking Distance to Transit

The maximum distance that people will walk to transit varies depending on the situation. Exhibit 4-12 shows the results of several studies of walking distances to transit in North American cities from the late 1960s through the 1980s. Although there is some variation between cities and income groups among the studies represented in the exhibit, it can be seen that most passengers (75 to 80% on average) walked 0.25 mi (400 m) or less to bus stops. At an average walking speed of 3 mi/h (5 km/h), this is equivalent to a maximum walking time of 5 min. A 2010 study in Montréal found somewhat longer walking distances: about half of those walking to bus stops walked more than 0.25 mi (*24*).

Exhibit 4-12
Walking Distance to Bus Stops



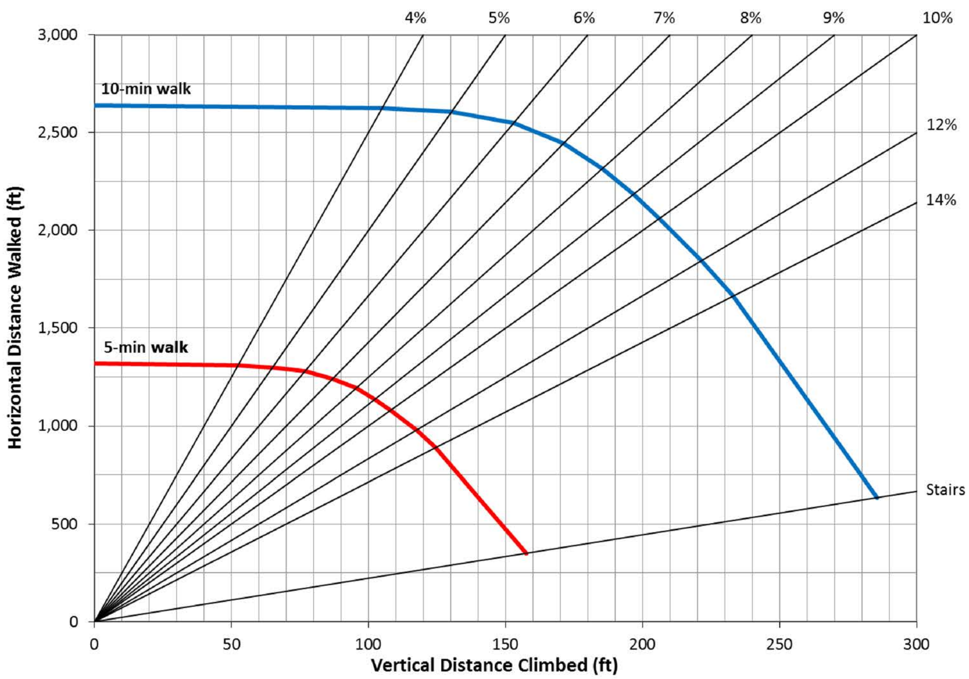
Sources: Atkinson (*31*), Lam and Morrall (*32*), Peterson (*33*), and Shortreed and Maynes (*34*).
Note: A metric version of this exhibit appears in Appendix A.

The walking times and distances to local bus stops can be at least doubled for rapid transit stations, where about 50% of walk-access passengers walk more than 0.5 mi (800 m) to the station (*24–28*). However, one study in the San Francisco Bay Area found that employment sites within 0.25 mi of a rail station had significantly higher transit usage rates than sites located between 0.25 and 0.5 mi, and that usage dropped precipitously after 0.5 mi. Many sites were in suburban areas with poor pedestrian environments, and it is unclear whether the results are due to the pedestrian environment or because passengers are more sensitive to access length at the destination end of their trip (*29*). A 2005 WMATA survey found that 35% of office workers on average used rapid transit for their commute trip when their office was located at a station entrance, with the percentage falling approximately 1% per 100 ft (30 m) of distance between the office and the station entrance (*30*).

BRT service that emulates the quality of rapid rail transit—frequent service throughout much of the day, relatively long stop spacing, distinct stations with a variety of passenger amenities, etc.—is expected to have the same walking access characteristics as other forms of rapid transit. However, at the time of writing, insufficient research had been conducted in the U.S. to confirm this expectation.

Other factors can reduce the distance that people will walk to transit stops. A poor pedestrian environment, discussed below, discourages pedestrian travel. The elderly typically do not walk as far as younger adults. Finally, people will tend to walk shorter distances in hilly areas, due to the effort involved. Exhibit 4-13 shows the results of a study in Pittsburgh on the relationship between walking speeds and grades. It can be seen that at grades of 5% or less (5 ft climbed for each 100 ft traveled horizontally), grades have little impact on travel speed, but that above 5%, the distance traveled within 5 or 10 min (0.25 mi/400 m or 0.5 mi/800 m on level terrain) goes down.

Exhibit 4-13
Effect of Grade on Distance Walked



Source: Municipal Planning Association (*35*).
Note: A metric version of this exhibit appears in Appendix A.

Pedestrian Environment

Even when a transit stop is located within a reasonable walking distance of one's origin and destination, the walking environment may not be supportive of transit. Studies of the relationship between urban form and walking have found that sidewalk availability, intersection density, and presence of retail are correlated with higher levels of walking to transit, while higher vehicle volumes and speeds and large parking lots around stations are associated with lower levels of walking (*36–38*).

The built environment, ability to cross the street safely, and personal security concerns all influence passengers' ability to walk to transit service.

Pedestrian safety is also an important factor. Wide or busy streets without safe and convenient crossing opportunities discourage pedestrian travel. Street-crossing difficulty poses particular difficulties for transit operators: an arterial street generally provides better transit speeds, but potential passengers using stops along the street must cross the street at some point during their round trip—either when they depart or when they return—and may not be able to easily access bus stops between signalized crossing points. One study found that the most important access factor for pedestrians after distance was safety. Approximately half of respondents rated it as "very important" to have traffic devices present and traffic driving at safe speeds, which was a higher rate than having sidewalks in good repair or aesthetic considerations (*28*).

Related to personal security, a study of access trips to light rail stations showed that higher crime levels at the station reduced the likelihood of walking to transit (compared to other access modes), particularly for female riders (*39*).

Street Patterns

A neighborhood's street pattern may affect transit access. A grid street pattern, such as those found in older cities, offers direct access between streets with transit service and the surrounding neighborhoods. When service is offered on parallel streets, some locations may have a choice of routes to use for a particular trip, resulting in a higher quality of service. On the other hand, subdivisions that back onto streets with transit service, with only one way in and out, will generally have a much smaller proportion of their residences located within a 0.25-mi (400-m) walking distance of a transit stop, even when the majority of the subdivision is located within 0.25 mi air distance of one or more transit stops.

Walking distances to transit may be considerably greater than straight-line ("air") distances.

Americans with Disabilities Act (ADA) Considerations

Passengers with disabilities often must have sidewalk facilities and curb cuts on their routes to and from transit stops to have the ability to access fixed-route transit service. Stops, stations, and transit vehicles must also be accessible. Without these facilities and provisions, passengers with disabilities must rely on paratransit service, which generally provides customers with fewer choices in travel times and usually costs substantially more for transit operators to provide.

Coordination between transit agencies and public works agencies is desirable to make sure transit access is prioritized.

Pedestrian Access Summary

TCRP Report 153 (*25*) lists the following issues as being essential in designing pedestrian access to transit service:

- *Directness and speed of route*—Pedestrians want direct walking routes, with minimum delays when crossing streets.

- *Safety and security*—Pedestrians need to perceive that their route is secure and visible to other road users, particularly in the evening. Highway safety is also important, particularly when crossing busy roadways.
- *Pedestrian-friendly design*—Lighting, building setbacks and orientations, and sidewalks are important determinants of whether pedestrian feel like “unwelcome guests” or perceive that the street is designed to meet their needs. Pedestrian facilities should be designed at a “human scale.”
- *Information*—New, occasional, and visiting travelers particularly need wayfinding information to reach local destinations.

Bicycle Access

According to *TCRP Report 153* (*25*), bicycle access to rapid transit stations is an increasingly important concern for transit agencies. Moreover, transit agencies located in urban areas where cycling is rapidly increasing are more likely to be actively engaged in efforts to improve bicycle access to transit. Transit agencies typically wish to achieve two goals related to bicycle access: (*a*) increase total bicycle access to support transportation agency and community goals for higher bicycle ridership and (*b*) establish effective means of accommodating bikes within the transit system, whether through bicycle storage facilities at the station or on board transit vehicles. These two goals are not always compatible, as increasing bicycle access also has the potential to overwhelm transit system passenger capacity when passengers choose to bring their bicycles with them, and bus-mounted bicycle rack use can increase dwell times at stops.

Integrating Bicycles with Transit

TCRP Synthesis 62 (*40*) provides a comprehensive review of bicycle integration policies at transit agencies. The review determined several key factors in determining the effectiveness of bicycles serving as an access mode to public transit:

- Bicycle facility availability and maintenance;
- Bicycle parking security;
- Restrictions and rules with regard to bicycles on transit vehicles;
- Marketing, awareness, education, and public support;
- User demographics;
- Climate; and
- Transit system design.

Key conclusions and findings of *TCRP Synthesis 62* include:

- Bicycle services help attract more transit riders by extending the transit system’s catchment area and by providing greater mobility to customers at the beginning and end of their transit trips.
- Several transit agencies believed that their bicycle services help decrease automobile traffic congestion, reduce air pollution, and improve the public image of transit.
- Compared with the capital costs of buses, rail cars, and automobile parking facilities, it is relatively inexpensive for transit agencies to purchase bicycle

equipment, such as bike racks on buses, bike hooks in rail cars, and bike racks and lockers at transit stations.

- Transit agencies have generally experienced few maintenance problems with their bicycle services. Problems reported included obtaining replacement parts for broken bus bike racks, abandoned bicycles in bicycle racks, bus bicycle racks interfering with windshield wipers, and the need to remove the bus bicycle rack when a bus is towed.

Bicycles on Transit

The predominant approach for integrating bicycles and transit in the U.S. is for bicyclists to bring their bicycle with them on board transit vehicles (Exhibit 4-14). In 2011, about 74% of new U.S. buses were equipped with exterior bicycle racks, up from 32% in 2001 (*41*). Bicycle racks have been popular with passengers, but they frequently run up against capacity constraints, typically two or three bicycles for each bus on a front rack, or three to four bicycles per light rail car interior (*42*).

Another consideration for higher-volume transit systems is that bicycles brought on board transit vehicles (BRT vehicles or rail cars) take up space on the station platform and in the vehicle that could be used by other passengers. A bicycle held horizontally occupies 11.8–16.6 ft^2 (1.10–1.54 m^2) (*43*), which is roughly the space taken up by 5 to 7 large adult males with heavy clothing. Bicycle hooks inside rail cars (Exhibit 4-14[a]) allow bicycles to be stored vertically, which reduces their space requirements, but they still occupy multiple passengers' worth of space. For this reason, some rapid transit systems prohibit bicycles during peak hours, at least in peak directions. A number of European transit operators require the purchase of a separate ticket for bicycles brought on board commuter trains.

Alternatives to bringing bikes on board transit vehicles include providing bicycle storage at the boarding transit stop and bike-sharing programs. An analysis of (*a*) the travel behavior of individuals, (*b*) the accompanying urban form characteristics, (*c*) individual preferences related to cycle–transit facilities, and (*d*) economic costs and technological feasibility suggest that transit agency investment in more attractive bicycle storage facilities would prove most cost effective in many cases (*42*). Bicycle storage options at transit stops and stations are discussed in more detail in Chapter 10, Station Capacity (page 10-36).

Bicycle Access Trip Lengths

Typical bicycling speeds are approximately 12 to 15 mi/h (20 to 25 km/h), or about four to five times higher than walking speeds. This speed advantage allows bicyclists to access transit lines much farther away from their origin or destination than they could if they walked, as long as a safe bicycling environment exists. There are limited available data on bicycle access sheds. However, a study of commuter rail access suggests that bicycle access peaks at distances between 1.0 and 1.25 mi (1.6 to 2.0 km) (*36*).

Exhibit 4-14
Onboard Bicycle Facility Examples

(a) LRT bike hook (Portland)

(b) BRT interior bicycle storage (Eugene)

(c) Bus-mounted bicycle rack (Honolulu)

(d) Bikes on ferry (Larkspur, California)

Automobile Access

As distance from the trip origin to transit service increases, more passengers use automobiles as an access mode, as illustrated conceptually in Exhibit 4-15. In particular, the automobile is the primary access mode for transit modes such as commuter bus and commuter rail that serve lower-density areas and rely on park-and-ride lots to focus demand on a small number of locations.

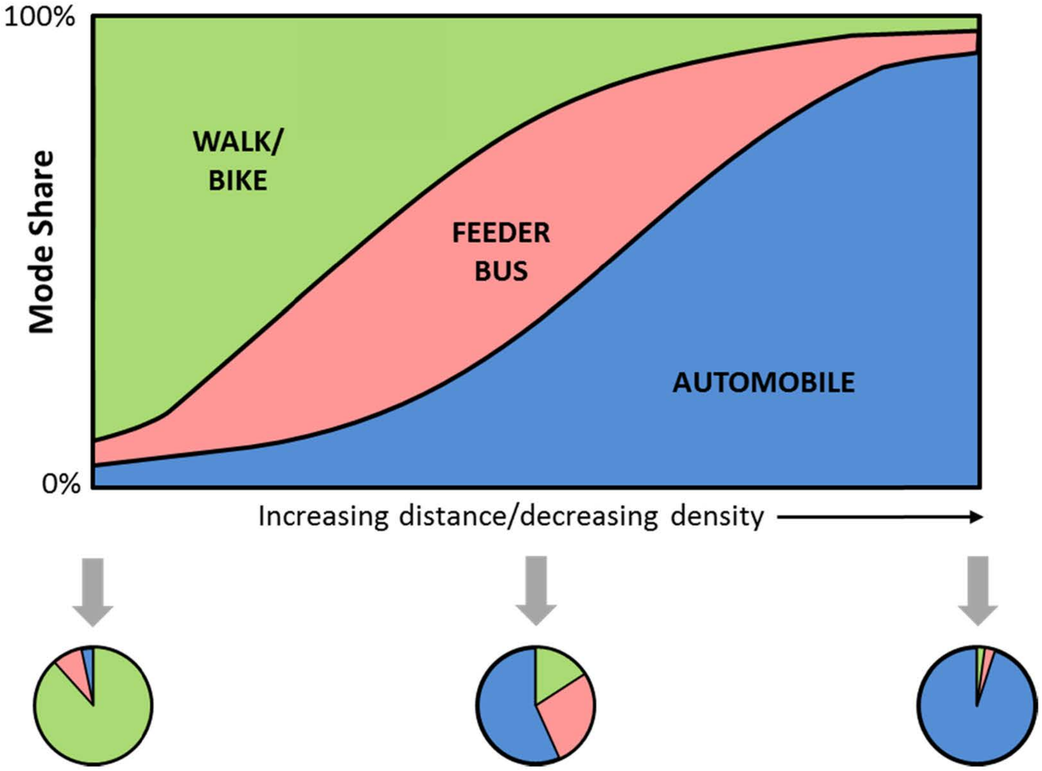


Exhibit 4-15
Conceptual Illustration of Effect of Distance on Transit Access Mode Choice

Source: *TCRP Report 153* (*25*).

An Overview of the Park-and-Ride User

Surveys of park-and-ride users in the Sacramento, Northern Virginia, Chicago, Seattle, and Phoenix regions identified the following characteristics of park-and-ride users at successful park-and-ride lots (*44*):

- Park-and-ride users are choice riders;
- Park-and-ride users have significantly higher incomes than local bus riders;
- The majority of park-and-ride users (more than 60%) travel to the CBD for work more than four times per week;
- Parking at the destination is expensive;
- Convenient, frequent bus service is offered; and
- Most riders find park-and-ride facilities because they can see them from their regular commute routes.

Characteristics of a Successful Rapid Transit–Focused Park-and-Ride Lot

TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations (*25*) identifies the following characteristics of successful park-and-ride lots serving rapid transit stations:

- *Locate in advance of congestion.* Park-and-ride lots in combination with rapid transit lines generate the greatest use (and transit ridership) in travel corridors that experience the most intense traffic congestion (i.e., peak-hour peak-direction freeway speeds of less than 30–35 mi/h or 50–60 km/h). Park-and-ride facilities should intercept motorists in advance of congestion and before points of major route convergence. Sites near junctions of radial transit lines and beltways or major arterial roads can tap a wide catchment area. Access to the lot should be upstream of major congestion points.

- *Locate sufficiently far away from the city center.* Park-and-ride facilities should be located as far from the downtown area as practical to remove the maximum number of travelers [and vehicle miles traveled (VMT)] from roadways during peak periods. They generally should be located at least 5 to 8 mi (8 to 13 km) from the city center. They should be far enough away to compensate for the time spent changing travel modes. Increasing parking space on the fringes of the downtown area is not desirable, as it could divert existing passengers from feeder transit service and non-motorized access modes.
- *Serve low-density residential areas.* In general, population densities in park-and-ride catchment areas should be less than 4,000 to 6,000 persons per square mile (1,500 to 2,300 persons per square kilometer) or about 4 to 5 dwelling units per net acre (10 to 12 dwelling units per net hectare).
- *Serve multiple markets.* Most rapid transit–focused park-and-ride lots serve downtown travelers. However, there is a growing tendency to also serve other large activity centers along the rapid transit lines. The lots should be located between their catchment areas and major activity centers. Motorists will use facilities that can be easily accessed en-route, but are less likely to backtrack.
- *Locate in safe areas.* Park-and-ride facilities should be placed in areas that are perceived as safe by patrons. They should not be located in high-crime areas, or in settings that are considered unattractive by users.
- *Complement and reinforce land development.* Park-and-ride facilities should be compatible with the surrounding environments. Large facilities—especially open-lot parking—should be limited or avoided in town centers, areas of high population and development density, and locations where transit-supportive uses are planned or encouraged around stations. Where garages are built, they should be carefully integrated with their surroundings.
- *Provide fast and frequent rapid transit service.* Rapid transit should operate at frequencies of 10 to 12 min or less during peak periods, while frequencies up to 20 min are acceptable during midday hours. Headways of 20 to 30 min are acceptable for commuter rail and commuter bus service during commute hours.
- *Provide good roadway access.* Facilities should be accessible and visible from nearby freeways and arterial roadways.

Types of Park-and-Ride Facilities

Park-and-ride facilities are a type of intermodal transfer facility. They provide a staging location for travelers to transfer between the auto mode and transit or between a single-occupant vehicle and carpools or vanpools. Park-and-ride facilities can be classified by location or function as follows (*45*):

- *Informal park-and-ride lots* are transit stops where motorists regularly drive their cars and leave them parked on the street or on an adjacent property. These are often more difficult to discern than lots officially connected with a transit stop.
- *Joint use lots* share the transit parking with another land use (e.g., church, theater, shopping mall, special events center) whose peak parking activity occurs outside regular commuting hours. The park-and-ride activity can be either the secondary or primary use of the facility, depending upon the desired orientation and opportunity provided.
- *Park-and-pool lots* are typically smaller lots that are intended exclusively for the use of carpool and vanpool vehicles. These can be joint use or may be part of a development plan where the developer dedicates a number of spaces.
- *Suburban park-and-ride lots* are typically located at the outer edges of the urban area.
- *Transit centers* are facilities where interchange between local and express transit service occurs.
- *Satellite parking lots* are generally placed at the edge of an activity center to provide inexpensive alternatives to on-site parking within the activity center itself and to reduce traffic congestion within the activity center.

Larger park-and-ride lots will also often provide *kiss-and-ride* areas with short-term parking where passengers can be dropped off and picked up.

Park-and-Ride Market Areas

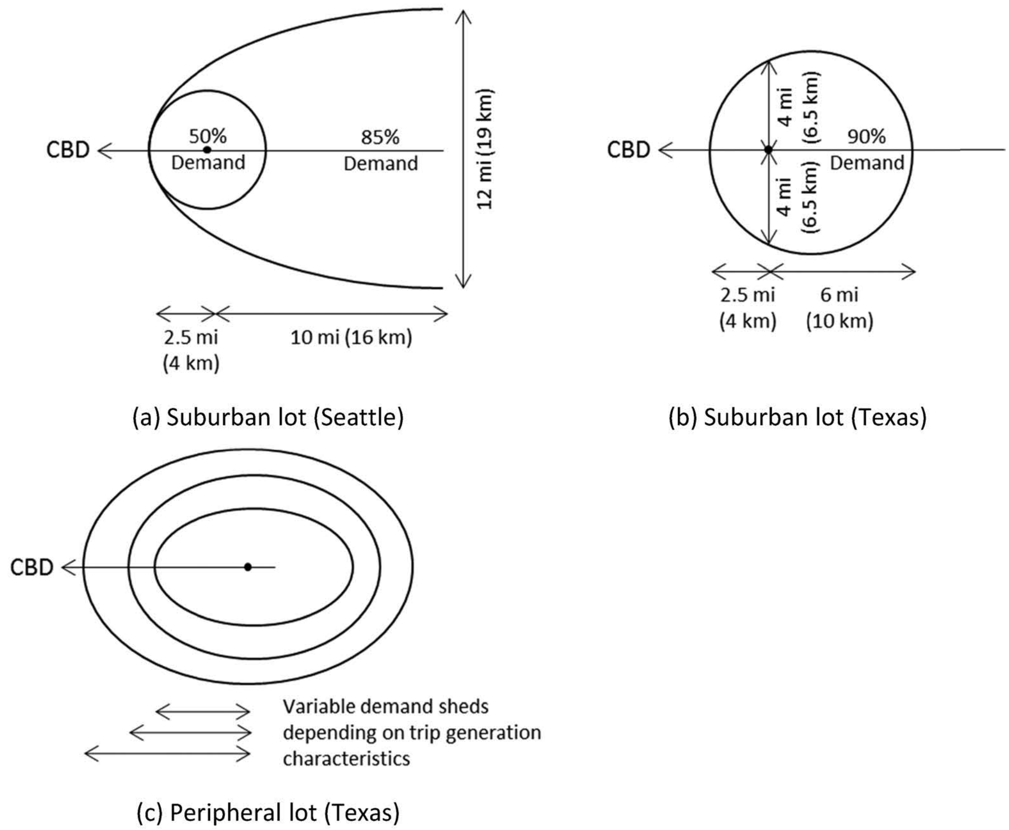
Because of the different characteristics of metropolitan areas, a standardized service shape that describes the entire park-and-ride lot market area that is suitable for application throughout North America is not feasible. However, some common characteristics of park-and-ride lots can be described.

A standardized service shape for park-and-ride lots is not feasible.

Patrons using a specific park-and-ride facility will be expected to come from a catchment area primarily upstream from the park-and-ride facility. Backtracking, the phenomenon of patrons who live between the park-and-ride lot and the employment destination who drive upstream to gain access to a lot for a downstream location is limited. However, where multiple major activity centers exist within an area and are served by a particular lot, passengers may arrive from all directions.

A study of Seattle-area park-and-ride lots found suburban lots generate about 50% of their demand from within a 2.5-mi (4-km) radius of the facility, and that an additional 35% comes from an area defined by a parabola extending 10 mi (16 km) upstream of the lot and having a long chord of 10 to 12 mi (16 to 20 km) (*46*). This market area is illustrated in Exhibit 4-16(a).

Exhibit 4-16
Illustrative Park-and-Ride Market Areas



Sources: Spillar (*45*); Parsons Brinckerhoff Quade & Douglass, Inc. (*46*); and North Central Texas Council of Governments (*47*).

Studies conducted in several Texas metropolitan areas suggest a parabolic model or an offset circular model would be appropriate for a park-and-ride service coverage area (*45*). This market area form is illustrated in Exhibit 4-16(b).

A study conducted for the North Central Texas Council of Governments found that the average market shed for "non-suburban" (i.e., peripheral) lots is typically more dispersed around a common center than the suburban park-and-ride types, as shown in Exhibit 4-16(c) (*47*). These findings were confirmed in a similar study from the Puget Sound region, which examined two lots that operate as peripheral park-and-ride facilities (*45*).

Finally, a study in Chicago found that approximately half of riders traveled less than 3 mi (5 km) from their origin to reach the parking facility, with only 30 percent traveling more than 6 mi (10 km). The length of the transit leg of the trip was greater than 10 mi (16 km) for nearly all trips (*48*).

Park-and-Ride Capacity

Where parking demand exceeds capacity, research shows that parking pricing and transportation demand management (TDM) measures can encourage auto drivers to switch to other access modes, but can run the risk of reducing ridership if not priced appropriately. While advanced parking management has not been shown to increase ridership significantly in the short term, it does benefit customer satisfaction, which may have long-term benefits (*49*).

Chapter 10, Station Capacity, provides example ranges of park-and-ride lot sizes for rail transit modes. It also summarizes existing knowledge about conceptually designing park-and-ride lots. *TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations* (*25*) provides more detailed guidance about planning and conceptually designing park-and-ride lots associated with transit stations.

Temporal Availability

Frequency and service span determine whether transit service is available when one wants to travel.

How often transit service is provided and when it is provided during the day are important factors in one's decision to use transit. The more *frequent* the service, the shorter the wait time when a bus or train is missed or when the exact schedule is not known, and the greater the flexibility that customers have in selecting travel times. The number of hours during the day when service is available (*service span*) is also highly important: if service is not provided at the times one desires to travel, transit will not be an option for that trip. These two factors in combination determine the temporal availability of transit service.

Frequency

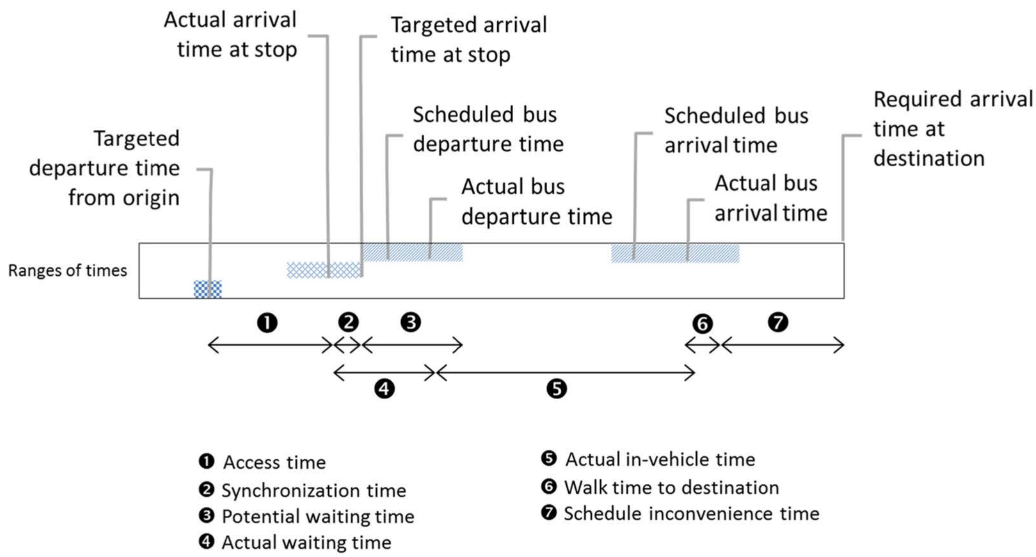
As was discussed in Section 2, Quality of Service Factors, frequency was consistently reported as the top factor influencing overall trip satisfaction in a survey administered in several cities around the U.S. (9). As will be seen in Section 4, Ridership and Service Costs, passengers also respond strongly in the form of increased ridership when frequency is improved, particularly when the previous service was relatively infrequent (*50*). The longer the headway, the more inconvenient transit service becomes, both because passengers have to plan their trip around transit service and because they incur more unproductive time during their trip. With long-headway service, passengers budget extra time into their trip to ensure they do not miss their transit vehicle and, as a result, have to wait the length of one headway for the next departure. Increasing frequency is expensive for transit agencies, so it is important to consider whether the land uses served by a transit route are capable of supporting higher frequencies.

Passenger Arrival Patterns

Frequency affects when passengers arrive at a bus stop. When headways are short, passengers know a transit vehicle should arrive shortly, so they tend not to consult schedules and instead arrive randomly. When headways are long, passengers will tend to consult the schedule, so they can plan their activities such that they arrive at the stop or station shortly before the scheduled departure time. The dividing line between short- and long-headway arrival patterns is fuzzy and depends in part on local service characteristics (e.g., schedule reliability, onboard seating availability). However, at headways of 10 min or less, most passengers tend to arrive randomly, while most passengers tend to schedule their arrival at headways of 15 min or more. Given the increasing availability of real-time arrival information in readily accessible forms (e.g., by smartphone, by texting a message to the transit agency's trip planner), more passengers may schedule their arrivals in the future, even with short headways.

As noted above, when headways are long, passengers budget extra time into their trip to ensure that they actually catch their desired transit departure, which affects their arrival time at a transit stop or station. Exhibit 4-17 depicts the different elements involved in a long-headway transit trip.

Exhibit 4-17
Components of a Long-Headway Transit Trip



During the first stage of her trip, the passenger leaves her trip origin (e.g., home) and travels to the transit stop or station. A passenger who makes the same trip regularly will be familiar with the reliability of the service and will try to arrive at the stop in time to catch even an early-departing vehicle. *TCRP Report 113* suggests that a reasonable passenger will target her arrival to catch a 2nd percentile departure time (*51*). Because a person's routine varies from day to day and because of day-to-day variability in the *access time* required to travel from the trip origin to the stop, there will be a range of times when the passenger will arrive and the passenger will arrive ahead of the targeted time on most days. The difference between the actual and targeted arrival times at the stop is known as *synchronization time* and is experienced as extra waiting time at the stop (*51*).

If the transit service is not perfectly reliable, there will be a range of times when the transit vehicle could depart on any given day. *TCRP Report 113* suggests that passengers' planned or *potential waiting time* is the time between their targeted arrival time at the stop and the 95th percentile departure time (thus assuming that passengers do not want to be late more than 5% of the time) (*51*). The actual departure time will usually be closer to the scheduled time, so the *actual waiting time* will be the difference between the arrival time at the stop and the departure time of the transit vehicle. With access to real-time information, a person can potentially plan around a late departure (e.g., by leaving his origin later or by running an errand on the way), making better use of the time than simply waiting at the transit stop.

In the next stage of the trip, the passenger rides on the vehicle to her destination. The *in-vehicle time* will vary from day to day, unless the service is perfectly reliable. Given the potential variation in departure times from the boarding stop and the potential variation in travel times to the destination, there is a range of potential arrival times at the destination stop. A passenger will pick the specific trip to travel on based on her knowledge of the *walk time* from the destination stop to the destination, her knowledge of the trip's travel time reliability or the reliability of the transit agency's service in general, and the importance of arriving at the destination on time. This typically results in *schedule inconvenience time,* where the passenger arrives at the destination earlier than desired (*51*). This time may be used productively in some cases (e.g., starting work earlier) or it may not (e.g., sitting in the doctor's waiting room or waiting to transfer to the next transportation service used in the trip).

Compared to a long-headway trip, a short-headway trip eliminates synchronization time (because the passenger shows up at random) and schedule inconvenience time is reduced, because departures occur more frequently and passengers can choose trips that arrive closer to their desired time. As a result, the time required to make a trip is reduced with higher-frequency (shorter-headway) service.

Service Span

Service span determines the potential markets that transit serves. The longer the span, the greater the variety of trip purposes that can be served. A 12-hour weekday service span, for example from 6 a.m. to 6 p.m., serves traditional commute trips and midday trips (e.g., shopping, medical appointments, social visits). A longer span would allow additional types of trips to be served—for example, retail employees who work in the evening or students who take night classes. A longer span needed to serve a particular market (e.g., office workers) gives those customers travel flexibility, particularly for their return trip (e.g., to work late, to run errands after work).

Information Availability

Riders need to know where and when transit service is available and how to use it.

Passengers need to know how to use transit service, where to go to access it, how to pay their fare, where to get off near their destination, whether any transfers are required, and when transit services are scheduled to depart and arrive. Without this information, potential passengers will not be able to use transit service, even though it would otherwise be an option for their trip. Visitors to an area and infrequent transit users (e.g., people who use transit when their car is being serviced) particularly need this information, but they can be the most difficult people to get information to. Even regular transit users may require information about specific routes when they need to travel to a location they rarely visit.

Timely and correct information is also vital under other circumstances:

- When regular service adjustments are made, such as schedule changes or route modifications;
- When temporary service changes are required, for example, due to road construction or track maintenance; and
- When service problems arise, so passengers know the nature of the problem and have enough information to decide how to adjust their travel plans.

Information can be provided to passengers by a variety of means:

Information must be available in accessible formats.

- *Printed, distributable information,* such as timetables, maps, service change notices, rider newsletters, etc., preferably available at a number of locations;
- *Posted information,* such as system maps posted at stations or on vehicles, or notices of out-of-service elevators;

- *Audible announcements* of stops and stations, train directions, fare zone boundaries, etc., which assist not only passengers with visual impairments, but also passengers unfamiliar with the route or area;
- *Visual displays* to assist passengers with hearing impairments and to supplement onboard announcements that may be muffled by other noise;
- *Transit agency staff,* such as station agents at transit stations, or *tourist information staff* at visitor centers;
- *Telephone information*, which can be provided by voice calls to a transit agency information line during business hours, automated phone menus available 24 hours a day, or by texting a short message to receive schedule or fare information;
- *Online information,* available 24 hours per day to anyone with Internet access;
- *Smartphone apps,* which can provide trip planning functions, fare information, and other kinds of transit information based on a person's current location; and
- *Transit infrastructure,* such as shelters, signs directing motorists to park-and-ride lots, and bus stop signs that indicate the presence of service to people not currently using transit.

No matter how passengers obtain information, it should be correct and up to date. Schedule information posted at stops, for instance, should be updated each time the schedule is updated. Information provided to passengers by transit agency employees during service disruptions should be as accurate and complete as possible under the circumstances, but should avoid being too specific (e.g., the train will be underway in "X" minutes) when there is the possibility that the circumstances could change.

Real-time information reassures passengers and lets them make informed choices.

Real-time information is useful for reassuring passengers about when the next vehicle will arrive. For example, if a bus does not arrive at its scheduled time, a passenger arriving at the stop shortly before that time will not know whether the bus left early, is running behind schedule, or is not in service. In addition, knowing that there will be a wait until the next bus arrives allows passengers to decide whether to run an errand or take a different bus rather than wait at the stop. Finally, when vehicle bunching occurs, knowing when the following vehicles will arrive is also useful: when passengers know that another vehicle will arrive in 1 or 2 min, some will choose not to board the first, typically crowded, vehicle in favor of a later, less-crowded vehicle. This helps spread out passenger loads among the vehicles and may help keep the lead vehicle from falling further behind schedule.

Capacity Availability

Insufficient capacity can impact transit service availability. If a bus or train is full when it arrives at a stop, transit service is not available at that time to the people waiting there. The effective service frequency for these passengers is reduced from what is implied by the schedule, as they are forced to wait for the next vehicle or find another means of making their trip. Lack of available securement space, a non-functional wheelchair lift, or a non-functional station elevator will impact fixed-route service availability for persons with disabilities. In demand-responsive service, capacity constraints take the form of *service denials,* where a trip cannot be provided at the requested time, even though service is operated at that time. Courts have held that a pattern of service denials is not allowed under the ADA for ADA service required as a complement to fixed route service. However, service denials can be and are used by general public demand-responsive transit providers as a means of rationing capacity to control costs.

TRANSIT COMFORT AND CONVENIENCE

Passenger Loading

The ability to find a seat on a transit vehicle is an important passenger comfort factor for longer trips.

Transit is less attractive when passengers must stand for long periods of time, especially when transit vehicles are highly crowded. When passengers must stand, it becomes more difficult for them to use their travel time productively, which eliminates a potential advantage of transit over the private automobile. Crowded vehicles also slow down transit operations, as it takes more time for passengers to get on and off. In addition, rail passengers may try to hold doors open in order to squeeze more passengers onto the train, which delays trains even more and, in a worst case, can cause the train to be taken out of service if the door jams.

Many transit agencies assess the degree of passenger crowding on a transit vehicle based on a design load or occupancy for the vehicle. This load, which may vary by time of day, reflects a compromise between passenger comfort and moving as many passengers as possible with the least number of vehicles. The design load is typically determined by the number of available seats, plus an assumed number of standees based on providing a desired level of comfort (space) per standee. Some types of transit service, including commuter bus and rail service that typically serve long trips, transit vehicles that operate in high-speed mixed-traffic operations, and demand-responsive service, will typically try to provide a seat for every passenger. Other types of transit service will typically design for some standees—at least during peak periods.

As discussed in Section 2, Quality of Service Factors, passengers perceive crowded in-vehicle conditions as being more onerous than non-crowded conditions, particularly when they have to stand.

Reliability

Reliability includes both on-time performance and the evenness of headways between transit vehicles.

Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger's arrival time at a destination from day to day. As shown previously in Exhibit 4-17, reliability also affects a passenger's total trip time: if persons believe a transit vehicle may depart early, they may arrive earlier than they would otherwise to ensure not missing the bus or train. Similarly, if passengers are not confident of arriving at their destination on time, they may choose an earlier departure than they would otherwise, to ensure that they arrive on time, even if it means often arriving much earlier than desired.

Types of Reliability

Bus bunching has capacity impacts, as the offered capacity cannot be fully utilized.

Reliability encompasses both on-time performance and the regularity of headways between successive transit vehicles. Uneven headways result in uneven passenger loadings, with a late transit vehicle picking up not only its regular passengers but those passengers that have arrived early for the following vehicle, with the result that the vehicle falls farther and farther behind schedule and more passengers must stand. In contrast, the vehicles following will have lighter-than-normal passenger loads and will tend to run ahead of schedule. With buses, this "bunching" phenomenon is irritating both to passengers of the bunched buses and to passengers waiting for other buses who see several buses for another route pass by while they wait for their own bus. With signaled rail operations, bunched trains often have to wait at track signals until the train ahead of them moves a safe distance forward. The resulting unscheduled waits are not popular with passengers, particularly when no onboard announcements are given explaining the delay.

Causes of Unreliability

Reliability is influenced by a number of factors, some under the control of transit operators and some not. These factors include:

Factors affecting the reliability of transit service.

- *Traffic conditions* (for on-street, mixed-traffic operations), including traffic congestion, traffic signal delays, parking maneuvers, incidents, etc.;
- *Road construction* and *track maintenance,* which create delays and may force a detour from the normal route;
- *Vehicle and maintenance quality*, which influence the likelihood that a vehicle will break down while in service;
- *Vehicle and staff availability*, reflecting whether there are sufficient vehicles available to operate the scheduled trips (some vehicles will be undergoing maintenance and others may be out of service for various reasons) and whether sufficient operators are available on a given day to operate those vehicles;
- *Transit preferential treatments*, such as exclusive bus lanes or conditional traffic signal priority that operates only when a bus is behind schedule, that at least partially offset traffic effects on transit operations;
- *Schedule achievability*, reflecting whether the route can be operated under usual traffic conditions and passenger loads, with sufficient layover time provided for operators and sufficient recovery time to allow most trips to depart on time even when the previous trip arrived late at the end of the route;
- *Line merges,* on rail systems, where one train arrives at a merge point behind schedule and creates a cascading series of delays to subsequent trains;
- *Evenness of passenger demand,* both between successive vehicles and from day to day for a given vehicle and run;
- *Differences in operator driving skills* (*52*), route familiarity, and adherence to the schedule—particularly in terms of early ("hot") running;
- *Wheelchair lift and ramp usage,* including the frequency of deployment and the amount of time required to secure wheelchairs;
- *Environmental conditions,* such as snow, ice, extreme heat or cold, or leaf fall;
- *Route length and the number of stops,* which increase a vehicle's exposure to events that may delay it—delays occurring earlier along a route result in longer overall trip times than similar delays occurring later along a route (*53, 54*); and
- *Operations control strategies* used to react to reliability problems as they develop, thus minimizing the impact of the problems (*55*).

Operational Control and Scheduling Measures to Improve Reliability

A study of a short-headway tram line in The Hague, The Netherlands (*56*) compared schedule-based and headway-based holding strategies. A schedule-based strategy holds early transit vehicles at a timepoint to maintain the schedule. A headway-based strategy holds transit vehicles as needed to maintain a desired spacing between vehicles. Schedule-based holding was found to be more effective when no maximum holding time was applied. With a maximum holding time of 60 s, there was no difference in the effectiveness of the two holding strategies. The improved reliability due to holding was found to reduce crowding or to allow a smaller capacity slack when scheduling trams.

Inserting slack into the schedule to improve a route's reliability does not necessarily increase a route's round-trip cycle time (a key determinant of vehicle needs for a route and thus operating costs) because time spent holding at timepoints can be subtracted from time spent holding on a layover (*57*).

Travel Time

As was seen previously in the section on value of time, passengers' travel time is an important convenience factor, and different portions of a trip may seem to pass more slowly or be more onerous than time spent in a transit vehicle. Total trip time includes access time from the trip origin to a transit stop or station, waiting time for a transit vehicle, travel time on board the vehicle, potentially transfer time and additional in-vehicle time, and walking time from a transit stop or station to the destination.

Because it is not possible to provide a one-seat trip between every possible combination of origin and destination, except in the smallest communities, transfers are often a necessary part of a transit trip. Each transfer adds to a passenger's total trip time, although the transfer time can be minimal when headways are short or when timed transfers are used. Introducing a transfer into what was previously a one-seat service may have a net positive benefit for passengers, if the new feeder-and-trunk service allows for higher frequencies or other passenger benefits compared to the previous service (*50*).

Transfers increase the possibility that a missed connection will occur, which would lengthen a passenger's trip by the amount of one headway on the connecting line. Transfers can also increase the complexity of a transit trip for first-time passengers.

Safety and Security

Passengers' perceptions of safety must be considered in addition to actual conditions.

Riders' perceptions of the safety and security of transit, as well as actual conditions, enter into the mode choice decision. *Safety* involves the potential for being injured while using transit (e.g., crashes, slips and falls). *Security* involves the potential for becoming the victim of a crime while using transit. It also covers irritants, such as encountering unruly passengers or having to listen to someone else's music, that may not be an actual threat but nevertheless makes passengers uneasy that the system's code of conduct is not being enforced.

Security at transit stops can be improved by placing stops in well-lit areas and by having well-marked emergency phones or help points available. Passengers may also feel more comfortable when other passengers are around (i.e., when one is not the only passenger on the car of a train or the only one waiting at a stop). Transit systems use a variety of methods to enhance security on board transit vehicles, including having uniformed and plainclothes police officers ride transit, establishing community volunteer programs, providing two-way radios and silent alarms for emergency communication, and using surveillance cameras.

Several studies of real-time information have found that passengers feel safer as a result of having the information, particularly after dark (*58, 59*). Studies in Great Britain have also found reductions in anxiety and stress as a result of having real-time information (*23*).

Cost

Free parking at a worksite is a disincentive to transit use.

Potential passengers weigh the cost and value of using transit against the out-of-pocket costs and value of using other modes. Out-of-pocket transit costs consist of the cost of the fare for each trip or the cost of a monthly pass (and possibly the cost of parking at a station), while out-of-pocket automobile costs include road and bridge tolls and parking charges. Other automobile costs, such as fuel, maintenance, insurance, taxes, and the cost of buying an automobile generally do not occur for individual trips and thus usually do not enter into a person's consideration for a particular trip. Thus, if a person does not pay a toll to drive someplace and free parking is provided at the destination, transit will be at a disadvantage because there will be no immediate out-of-pocket cost for driving, while there will be for transit. Some transportation demand management (TDM) techniques seek to overcome this obstacle by encouraging employers who provide free parking (in effect, subsidizing the true cost of providing parking) to also provide subsidized transit passes or other means of encouraging transit use as an alternative to the private automobile.

Appearance and Comfort

Having clean, attractive transit stops, stations, and vehicles improves transit's image, even among non-riders. For example, the presence of shelters can help non-users become aware of the existence of transit service in the areas that they normally travel past in their automobiles. On the other hand, a dirty or vandalized shelter or vehicle can raise questions in the minds of non-users about the comfort and quality of transit service, and about other aspects of the service, such as maintenance, that may not be as obvious. Some transit systems have established standards for transit facility appearance and cleanliness and have also established inspection programs (*5*).

Passengers are also interested in personal comfort while using transit, including

- Appropriate *climate control* for local conditions, such as heating in the winter and air conditioning in the summer;
- *Seat comfort,* including seat size, amount of padding, and leg room; and
- *Ride comfort,* including the severity of acceleration and braking, vehicle sway, odors, and vehicle noise. Ride comfort is particularly important for older passengers and persons with disabilities.

Amenities: frills or necessities?

Many elements of transit infrastructure help make transit comfortable for passengers and make transit more competitive with the automobile. This infrastructure is often referred to as *amenities*; however, some have argued that the term "amenities" implies something extra and not necessarily required. Passengers sweltering on a non–air conditioned bus on a hot day would likely not agree that air conditioning is a frill, instead of a necessity.

The types of amenities provided are generally related to the number of boarding passengers at a stop. Examples of transit amenities include the following (*60*):

- *Benches,* to allow passengers to sit while waiting for a transit vehicle.
- *Shelters,* to provide protection from wind, rain, and snow in northern climates and from the sun in southern climates. In cold climates, pushbutton-operated overhead heaters are sometimes provided at major transit centers or stations.
- *Lighting,* to improve passenger security.
- *Informational signing,* to identify the routes using the stop, their destinations (both intermediate and ultimate), and/or scheduled or actual arrival times.
- *Trash receptacles,* to reduce the amount of litter at the transit stop. Because of security concerns, some transit agencies are choosing to remove them, though.
- *Telephones,* to provide the ability to make emergency calls. Telephones should be programmed to allow outgoing calls only to discourage loitering.
- *Vending facilities,* ranging from newspaper racks at commuter bus stops to manned newsstands, flower stands, food carts, transit ticket and pass sales, and similar facilities at rail stations and bus transfer centers.
- *Air conditioning* on transit vehicles, to provide a comfortable ride on hot and humid days, as well as *heating* in stations and on vehicles in colder climates.

TCRP Report 19 (*60*) *provides guidelines for designing, locating, and installing transit amenities.*

Customer Relations

Transit agency staff are the public face of the agency and driver friendliness or helpfulness frequently appears in surveys as an important customer satisfaction factor. Helpful staff can help offset some the effects of poor service quality, while staff with poor attitudes can damage the impression of the transit agency with both passengers and the public at large (*11*). British research indicates that a good interaction with a driver upon boarding a bus provides the same positive value of time effect as having seating available at the bus stop (*11*).

4. QUALITY OF SERVICE, RIDERSHIP, AND SERVICE COSTS

Improving the quality of service can result in ridership growth, but it may also entail added costs. Transit agencies need to consider both issues as they plan service and allocate resources. In some cases, measures to improve aspects of quality of service—in particular, speed and reliability—can result in operating cost savings or opportunities to further improve service quality (e.g., frequency) that result in additional ridership growth. This section discusses the impact of quality of service changes on ridership and operating and capital costs.

QUALITY OF SERVICE AND RIDERSHIP

Improvements in quality of service can result in increases in ridership, which in many cases, can result in an improvement in a transit agency's financial performance. Of course, if ridership increases sufficiently, additional service must be added and additional costs will likely be incurred. The opposite result is often true in ADA paratransit service, where most trips are made with only one passenger: increased ridership results in increased transit agency costs, without the economies of scale that apply to fixed-route service (*5*).

The impacts of quality of service on ridership are usually estimated using one of two methods. *Discrete choice models* estimate the probability that a traveler will use a particular mode choice (e.g., transit) from a variety of mode choice options available. Given a known number of travelers in an area, the number of people using each mode can thus be estimated. *Elasticity* relates the observed percentage change in ridership to the percentage change in some other factor (e.g., fares, headways, etc.).

A presentation of detailed procedures for estimating ridership is beyond the scope of this manual, and readers are referred to textbooks on discrete choice models for further information. However, some general guidelines on the impacts of quality of service changes on ridership are presented below, based primarily on information from the *TCRP Report 95: Traveler Response to Transportation System Changes* series (*61*). This reference also presents formulas for applying elasticities; all of the elasticities presented below are midpoint arc elasticities.

Response to Service Frequency Changes

Ridership is more responsive to changes in service frequencies when the existing service is infrequent (30-min headways or longer), in middle- and upper-income areas, and when the distances traveled are short enough that walking is an option. Ridership is less responsive when service was already relatively frequent, in lower-income areas, and when most trips are long. All other factors being equal, climate (which affects passenger comfort while waiting for service), the condition of the local economy, the overall transit agency image, and the way the new service is marketed will also affect the amount of the response (*50*).

Observed elasticities generally range from 0.0 (no change in ridership) to +1.0 (i.e., a 1% increase in frequency results in a 1% increase in ridership), with an average elasticity in the range of +0.3 to +0.5. More recent observations have grouped around either +0.3 (mainly central city urban systems) or +1.0 (suburban systems with positive images undergoing planned, comprehensive service increases). Limited research suggests that improvements in hours of service can be as important as improvements in service frequency (*50*).

Commuter rail elasticities related to service frequency are generally higher than those for buses, in part because commuter rail frequencies tend to be relatively low. Observed *headway* elasticities range from –0.7 to –0.9 for headways greater than 50 minutes (i.e., a 1% increase in headway results in a 0.7 to 0.9% *decrease* in ridership), and from –0.4 to –0.6 at shorter headways. In contrast, light rail and heavy rail elasticities related to service frequency are typically less than those for buses because these rail modes already operate at relatively high frequencies (*50*).

Response to Reliability Changes

Reports of passenger responses to decreases in reliability are mostly anecdotal, indicating that ridership is lost when service is perceived to be unreliable. Part of this response can be attributed to additional wait time incurred when transit vehicles leave early or are late (or never arrive at all), and part can be attributed to passenger uncertainty, anxiety, and annoyance. However, a British study (*62*) found that transit lateness and reliability have little effect on demand. A U.S. study (*63*) found that it is difficult to screen out the many other factors that influence ridership, giving the example of a bus route where added running time improved the route's on-time performance from 65% to better than 85%, yet the route lost ridership.

London Transport has estimated that elasticities due to unplanned service losses (e.g., scheduled vehicle miles not operated) are 33% larger than elasticities related to planned service cuts (*64*). An analysis of automatic vehicle location (AVL) and automated passenger counter (APC) data in Portland, Oregon found that a 10% reduction in headway delay variation (the average absolute value of the difference between the actual and scheduled headway) on radial bus routes during the a.m. peak hour led to an increase of 0.17 passengers per trip per timepoint (*65*).

As discussed more in Chapter 5, Quality of Service Methods, reliability can be expressed in terms of excess wait time (the difference between the actual and scheduled departure time when a transit vehicle is late), which can be included as part of overall travel time or perceived travel time. Changes in reliability that reduce excess wait time thus decrease travel time and can be included in an analysis of ridership response to travel time changes (*8*).

Response to Travel Time Changes

TCRP Report 118: Bus Rapid Transit Practitioner's Guide (*66*) suggests a range of elasticities of -0.3 to -0.5 related to travel time, with -0.4 typical.

Response to Service Coverage Changes

Average elasticities of service expansions of existing systems (measured in terms of bus miles or bus hours) range from +0.6 to +1.0, with the higher values occurring in areas where the existing service level is below average, such as in small cities and suburbs, and during off-peak hours. (Note that existing ridership is often low in these situations, and that the same number of new passengers will result in a greater percentage increase in ridership when starting from a lower ridership level than from a higher ridership level.) Packages of improvements, combining better routes and schedules, with new buses and/or reduced fares have been found to do particularly well in attracting new ridership (*17*).

Studies of service expansions since the 1960s—whether by extending existing routes, or by adding reverse-commute or suburb-to-suburb routes—indicate a success rate (i.e., the service was retained after the experimental period) at or slightly higher than 50 percent. New bus routes take 1 to 3 years to reach their full patronage potential, while entirely new bus systems may take even longer. New residential and multi-purpose feeders to line-haul bus and commuter rail services tend to attract 100 to 600 daily trips after 2 to 3 years, while single-employer shuttles are in the range of 25 to 600 daily trips (*17*).

Response to Fare Changes

Peak-period riders, persons traveling to and from work, and captive riders are significantly less responsive to fare changes than others. Passengers in larger cities are less sensitive to fare increases than are passengers in smaller cities. Perhaps similarly, ridership is less sensitive in areas where transit is in a competitive price and service position relative to the automobile. Elasticities do not appear to be different for large fare changes compared with small changes, nor for fare increases versus fare decreases (*67*).

The average elasticity of bus fare changes is –0.40 (i.e., a 1% fare increase results in a 0.4% decrease in ridership). The elasticity of rapid transit fare changes is about half as great, averaging –0.17 to –0.18. Off-peak ridership sensitivity is generally twice as sensitive as peak ridership, as new or infrequent riders are attracted to transit as a result of fare decreases. Peak-period riders, with the exception of senior citizens, tend not to shift travel to off-peak periods in response to off-peak fare reductions. The average senior citizen fare elasticity is –0.21 (*67*).

With the exception of downtown free-ride zones, eliminating fares systemwide results in no greater increase in ridership than would be predicted from a 100% fare reduction. Downtown free-ride zones and free shuttles are attractive for lunchtime trips and often attract trips previously made by walking (*67*).

Response to Packages of Improvements

Studies of corridor ridership before and after the implementation of BRT service have found up to a 25% increase in ridership in the corridor beyond what would be expected simply from frequency and travel time improvements. It is hypothesized that other elements of BRT—exclusive running ways, branding, enhanced stops and stations, etc.—contribute to a "premium service" image that is attractive to passengers. *TCRP Report 118* provides a method for estimating the amount of additional ridership increase for a given package of BRT elements (*66*).

An evaluation of a package of "streamlining" improvements to selected frequent-service routes in Portland, including additional service hours, transit signal priority, curb extensions, and upgraded stops, along with real-time information at nine stops, found that ridership on the streamlined routes increased by 18.2%, compared to an increase in service hours of 16.3%. This represents an elasticity of 1.11, compared to the service hour elasticity of 0.3 observed on non-streamlined routes at the same time, suggesting that the package of improvements produced a greater ridership impact than could be accounted for by service hour changes alone (*68*).

QUALITY OF SERVICE AND SERVICE COSTS

Costs Associated with Frequency Changes

Operating costs are very sensitive to changes in frequency. All other things being equal (in particular, travel times or speeds), doubling the frequency on a line will result in the operating costs doubling. If the frequency is added during peak periods, additional vehicles will be needed to provide the service (assuming no reductions to service elsewhere) and additional infrastructure (e.g., new or larger maintenance facility) may eventually also be needed, both of which entail capital costs.

Driverless rail systems are also subject to increased operating costs with increased frequency. However, because the labor cost of a driver is not incurred with these systems (only power and maintenance costs), the operating cost increment to add frequency is less.

Some rail lines are designed economically, with signal and power systems designed to accommodate near- and mid-term planned headways. Increasing frequency beyond the design level on these lines will incur capital costs to upgrade these systems.

Costs Associated with Service Hour Changes

Increasing the hours of service increases operating costs, as transit vehicles are in service longer, with the corresponding costs to power them and (usually) to drive them. All other things being equal, a 20% increase in the hours operated over the course of the week will typically increase operating costs by 20%, whether the added hours come from extending hours of service by 2 hours a day on weekdays, or by providing 10 hours of new service on Saturdays. Depending on the terms of the contract with the drivers or the contracted service provider, it may cost more to add service at night or on weekends, compared to adding service during the day on weekdays.

There are typically no direct capital costs involved with increasing service hours during off-peak periods, as sufficient vehicles typically are available to provide the new service. Vehicles would receive extra use, which could require them to be replaced sooner and undergo scheduled maintenance more frequently.

Costs Associated with Service Coverage Changes

Operating costs associated with providing service to an area that has not received service before typically increase in proportion to the number of vehicle hours required to operate the route(s) serving the area. Similar to changes in frequency, additional transit vehicles may be needed to provide the additional service, and the capacity of maintenance facilities to accommodate the additional vehicles will need to be evaluated. Other capital costs include costs to install bus stop signage, shelters, landing pads, etc.

Costs Associated with Reducing Crowding

Vehicle crowding issues that are the result of too much demand (as opposed to crowding as a result of reliability issues) can be addressed in a number of ways. Adjusting the headway of individual trips to balance out demand can be done without increasing operating costs. If more capacity is needed, then three potential options exist:

1. Adding frequency to reduce the average load per trip. This entails all of the costs described above for frequency.

2. Using a larger vehicle while maintaining existing frequency. For example, substituting an articulated bus for a standard bus. This approach adds capital costs for the new vehicles. If the vehicles have not been used in the system before, then there will also be costs associated with training mechanics to work on the vehicles and potential costs to modify maintenance facilities to accommodate the vehicles and to stock a larger selection of spare parts. There will be a minor increase in operating costs, as larger vehicles are typically less fuel-efficient.
3. Using longer trains, for rail systems that have sufficient platform length to accommodate longer trains. Additional rail cars are required to provide the extra capacity and potentially extra storage space will be needed in yards. There will be an increase in operating costs to maintain the additional vehicles, along with a minor increase in costs to power them. Electrically powered rail systems may require an electrical system upgrade to provide sufficient power to operate the extra cars, which can entail substantial capital costs.

Costs Associated with Reliability Changes

The costs to address reliability issues depend on the cause(s) of reliability problems and the techniques selected to address them. Adding running time to the schedule may increase the line's cycle time to the point that an extra vehicle needs to be added to maintain the desired headway. Infrastructure improvements, such as bus lanes or traffic signal priority, have associated capital costs (and sometimes operating costs as well). *TCRP Synthesis 83* (*69*) describes the costs associated with a variety of transit preferential treatments.

Costs Associated with Travel Time Changes

As with reliability, the costs to provide travel time improvements depend on the method(s) selected to provide travel time savings: stop consolidation, fare collection changes, or infrastructure improvements. If sufficient time can be saved that a transit vehicle can be removed from service while keeping the existing headway, operating cost savings will result (or, alternatively, an opportunity will exist to improve service on another route at no added cost).

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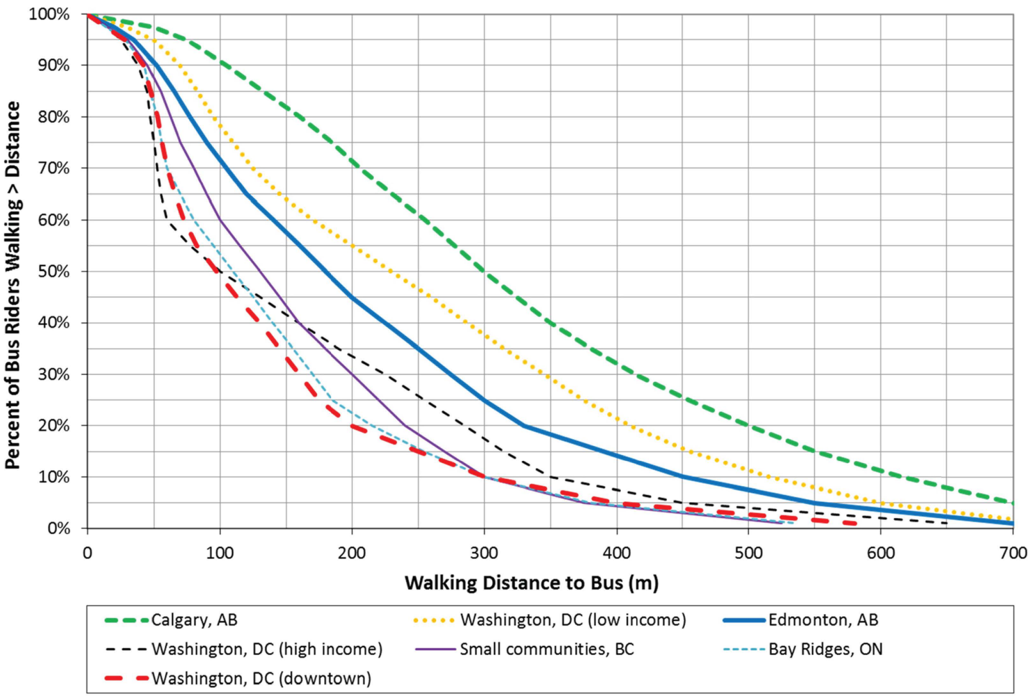
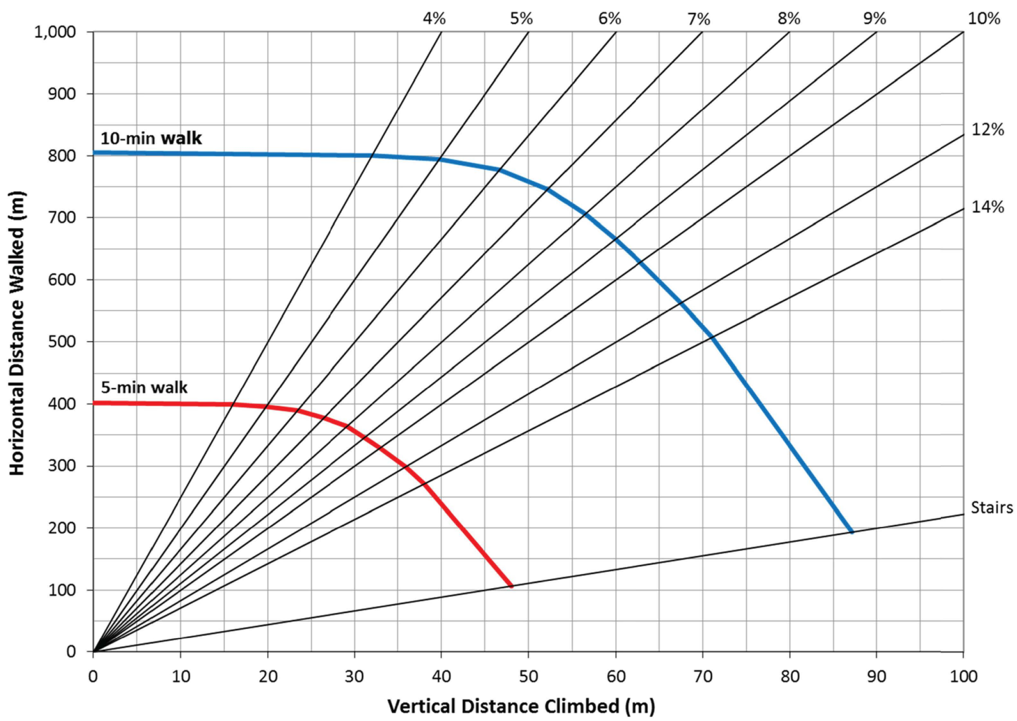
APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 4-12m
Walking Distance to Bus Stops



Sources: Atkinson (*31*), Lam and Morrall (*32*), Peterson (*33*), and Shortreed and Maynes (*34*).

Exhibit 4-13m
Effect of Grade on Distance Walked



Source: Municipal Planning Association (*35*).