PART 3
QUALITY OF SERVICE

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. QUALITY OF SERVICE FUNDAMENTALS

OVERVIEW

Quality of service reflects the passenger's perception of transit performance. The performance measures used to describe this perception are different from both the economic performance measures typically reported to the FTA and the vehicle-focused performance measures used in the *Highway Capacity Manual.* Quality of service depends to a great extent on the operating decisions made by a transit system within the constraints of its budget, particularly decisions on where transit service should be provided, how often and how long it is provided, and the kind of service that is provided. Quality of service also measures how successful an agency is in providing service to its customers, which has ridership implications. These implications were discussed in Part 1.

Organization of Part 3.

Part 3 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for measuring key aspects of quality of service. These aspects are ones that have been identified by a number of sources as being particularly important to passengers and are ones that are readily quantified. Part 3 also discusses other aspects of quality of service that may be important to the customers of a particular agency.

- *Chapter 1* discusses transit performance measures in general and contrasts passenger-based quality of service measures with other kinds of transit performance measures.
- *Chapter 2* discusses ways to measure key elements of quality of service.
- *Chapter 3* presents level of service (LOS) ranges for measures that address fixed-route transit availability and service provision and which are applicable to transit stops, route segments, and/or systems.
- *Chapter 4* presents level of service ranges for measures that address demand-responsive service availability and provision.
- *Chapter 5* contains references for material presented in Part 3.
- *Chapter 6* presents example problems that apply quality of service measures to real-world situations.
- *Appendix A* provides substitute exhibits in metric units for Part 3 exhibits that use U.S. customary units only.

Exhibits that also appear in Appendix A are indicated by a margin note like this.

Definitions

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

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

- *Transit performance measure:* a quantitative or qualitative factor used to evaluate a particular aspect of transit service.
- *Quality of service:* the overall measured or perceived performance of transit service from the passenger's point of view.

- *Transit service measure:* a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. It is also known as a *measure of effectiveness.*
- *Levels of Service.* Designated ranges of values for a particular service measure, such as "A" (highest) to "F" (lowest), based on a transit passenger's perception of a particular aspect of transit service.

The primary differences between performance measures and service measures are the following:

1. Service measures represent the passenger's point of view, while performance measures can reflect any number of points of view.
2. In order to be useful to users, service measures should be relatively easy to measure and interpret. It is recognized, however, that system-wide measures will necessarily be more complex than stop- or route-level measures.
3. Levels of service are developed only for service measures.

Levels of Service

The selection of LOS thresholds for each of the service measures presented in this manual represent the collective professional judgment of the TCRP Project A-15A team and panel. However, the LOS ranges—in particular, LOS "F" for fixed-route service and LOS "8" for demand-responsive service—are not intended to set national standards. It is left to local transit operators and policy agencies to decide how or whether to describe performance in terms of levels of service. It is also left to local decision-makers to determine which LOS ranges should be considered acceptable, given the unique characteristics of each agency and the community served. To aid in this effort, this manual provides guidance on the changes in service quality perceived by passengers at each LOS threshold.

Level of Service Framework

Fixed-Route Service

Chapter 3 divides fixed-route quality of service measures into two main categories: (1) availability and (2) comfort and convenience. The availability measures address the spatial and temporal availability of transit service. If transit service is located too far away from a potential user or if service does not run at the times a user requires it, that user would not consider transit service to be available and thus the quality of service would be poor. Assuming, however, that transit service is available, the comfort and convenience measures can be used to evaluate a user's perception of the quality of his or her transit experience.

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

- *Transit Stops:* measures addressing transit availability and comfort and convenience at a single location. Since these measures depend on passenger volumes, scheduling, routing, and stop and station design, performance measure values in this category will tend to vary from one location to another.
- *Route Segments/Corridors*: measures that address availability and comfort and convenience along a portion of a transit route, a roadway, or a set of parallel transportation facilities serving common origins and destinations. These measure values will tend to have less variation over the length of a route segment, regardless of conditions at an individual stop.

- *Systems*: measures of availability and comfort and convenience for more than one transit route operating within a specified area (e.g., a district, city, or metropolitan area). System measures can also address door-to-door travel.

Lower-level measures (e.g., stop-level) are also applicable at higher levels (i.e., the route or system levels). Combining the two performance measure categories with the three transit system elements produces the matrix shown in Exhibit 3-1.

Since route segments are composed of a series of stops, stop-level measures are also applicable at the segment level.

Exhibit 3-1
Quality of Service Framework: Fixed-Route

	Service Measures		
	Transit Stop	**Route Segment**	**System**
Availability	Frequency	Hours of Service	Service Coverage
Comfort & Convenience	Passenger Load	Reliability	Transit-Auto Travel Time

It is recognized that these measures may not always be sufficient to fully describe fixed-route service quality. Chapter 3 describes other measures that analysts may also wish to consider to supplement the measures listed above. Analysts may also find it helpful to present the service measures in the form of a transit "report card" that compares several different aspects of transit service at once.

Demand-Responsive Service

Demand-responsive service is delivered differently than fixed-route service, and its passengers have different service expectations than fixed-route passengers. As a result, a separate framework is provided for demand-responsive service measures. Chapter 4 uses the same categories of availability and comfort and convenience used in Chapter 3. However, because demand-responsive service has no designated stops, two aspects of availability and three aspects of comfort and convenience are presented, rather than measures for specific location types. No measure of service coverage is provided, as this is measured indirectly by the other two availability measures (i.e., there is no service span where there is no coverage). Exhibit 3-2 presents the quality of service framework for demand-responsive service.

Exhibit 3-2
Quality of Service Framework: Demand-Responsive

	Service Measures		
Availability	Response Time	Service Span	
Comfort & Convenience	On-Time Performance	Trips Not Served	DRT-Auto Travel Time

TRANSIT PERFORMANCE MEASURES

To get a sense of what quality of service is, it is useful to understand what it is not. Exhibit 3-3 illustrates one way that transit performance measures can be categorized and shows how quality of service fits into the spectrum of transit performance measures.

At the broadest level, there are a variety of performance measures that have been developed to describe different aspects of transit service. These measures can be organized into particular categories, such as service availability or maintenance and construction. *TCRP Report 88*(R17) identifies the following categories:

- *Availability*: measures assessing how easily potential passengers can use transit for various kinds of trips;
- *Service Monitoring*: measures that assess passengers' day-to-day experiences using transit;
- *Community*: measures of transit's role in meeting broad community objectives, and transit's impact on the community it serves;
- *Travel Time*: how long it takes to make a trip by transit, by itself, in comparison with another mode, or in comparison with an ideal value;

Exhibit 3-3
Transit Performance Measure Categories and Examples(R17)

PASSENGER ("QUALITY OF SERVICE") | AGENCY | VEHICLE/DRIVER | COMMUNITY

	PERFORMANCE MEASURE EXAMPLES	
TRAVEL TIME	• Transit-Auto Travel Time	• Transfer Time
AVAILABILITY	• Service Coverage • Service Denials	• Frequency • Hours of Service
SERVICE DELIVERY	• Reliability • Comfort	• Passenger Environment • Customer Satisfaction
SAFETY & SECURITY	• Vehicle Accident Rate • Passenger Accident Rate	• Crime Rate • % Vehicles with Safety Devices
MAINTENANCE & CONSTRUCTION	• Road Calls • Fleet Cleaning	• Spare Ratio • Construction Impact
ECONOMIC	• Ridership • Fleet Maintenance Performance	• Cost Efficiency • Cost Effectiveness
TRANSIT IMPACT	• Community Economic Impact • Employment Impact	• Environmental Impact • Mobility
CAPACITY	• Vehicle Capacity • Volume-to-Capacity Ratio	• Roadway Capacity
TRAVEL TIME	• Delay	• System Speed

Transit performance measures can represent the passenger, agency, driver/vehicle, and/or community point of view.

Travel time overlaps the vehicle/driver and passenger points of view.

- *Safety and Security*: the likelihood that one will be involved in an accident (*safety*) or become a victim of crime (*security*) while using transit;
- *Maintenance and Construction*: the effectiveness of the agency's maintenance program and the impacts of transit construction on passengers;
- *Economic*: measures of transit performance from a business perspective; and
- *Capacity*: the ability of transit facilities to move people and transit vehicles.

Some of these categories more directly affect passengers' experience while using transit than others. Each category can be assigned to one or more points of view, reflecting the primary viewpoint(s) of the measures in that category.

Agency point of view.

The *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 agency point-of-view—particularly economics and maintenance and construction—are ones of greater interest to agencies than to the other groups. These measures are also the ones that, at present, are more likely to be tracked by transit agencies.

One reason that 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 FTA's National Transit Database (formerly Section 15) annual reporting process. Most of the NTD measures relate to cost and utilization. These measures are important to the agency—and indirectly to passengers—by reflecting the amount of service an 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.

Vehicle/driver point of view.

The *vehicle/driver point of view* includes measures of vehicular speed and delay, such as those routinely calculated for streets and highways using the procedures given in the *Highway Capacity Manual.* This point of view also includes measures of facility capacity in terms of the numbers of transit vehicles or total vehicles that can be accommodated. Because transit vehicles carry passengers, these measures also reflect the passenger point of view: passengers on board a transit vehicle traveling at an average speed of 12 mph (20 km/h) individually experience this same average travel speed. However, because these vehicle-oriented measures do not take passenger loading into account, the passenger point of view is hidden, 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 as the single-occupant vehicle.

Community point of view.

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.

Quality of service focuses on the passenger point of view.

Quality of service focuses on those aspects of transit service that directly influence how passengers perceive the quality of a particular transit trip. These factors are discussed in the following sections.

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?

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

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, when one can get to and from the transit stops, when sufficient capacity is available to make the trip at the desired time, and when one knows how to use the service. 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, 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.

These factors can be summarized as shown below and as depicted in Exhibit 3-4 in the form of a flowchart:

- *Spatial availability*: Where is service provided, and can one get to it?
- *Temporal availability*: When is service provided?
- *Information availability*: How does one use the service?
- *Capacity availability*: Is passenger space available for the desired trip?

Comfort and Convenience

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

When all of the factors listed above are met, 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:

- How long is the walk? Can one walk safely along and across the streets leading to and from transit stops? Is there a functional and continuous accessible path to the stop, and is the stop ADA accessible?
- 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 one have to stand? Are there an adequate number of securement spaces? Are the vehicles and transit facilities clean?
- How much will the trip cost?
- How many transfers are required?
- How long will the trip take in total? How long relative to other modes?

Unlike the first decision—whether transit is an option for the trip—the questions listed above are not necessarily all-or-nothing. People have their own personal values that they apply to a given question, and each person will weigh the 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.

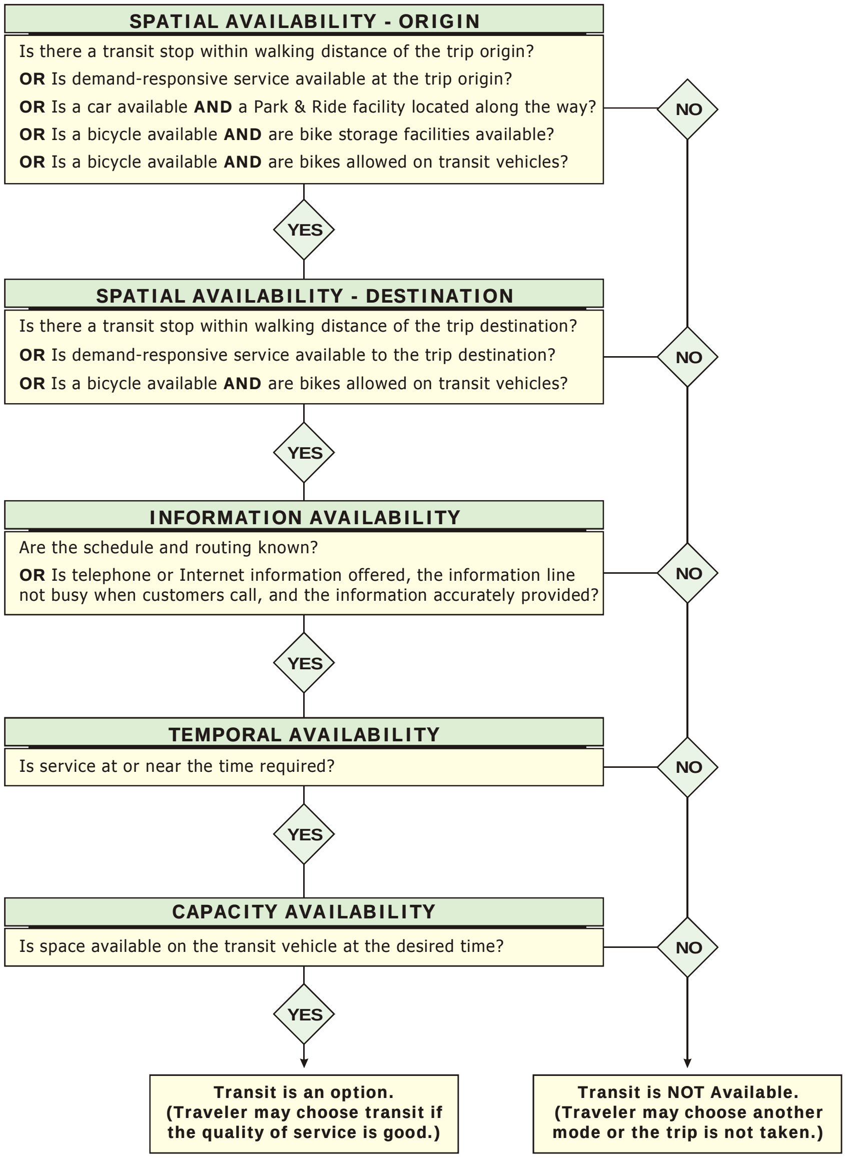


Exhibit 3-4
Transit Availability Factors

Service Delivery

Service delivery measures look at passengers' daily experiences using transit.

Service delivery assesses passengers' day-to-day experiences using transit—how well does the agency deliver the service it promises and how well does it meet customers' expectations? Even when transit service is available to someone, if a trip by transit is inconvenient or uncomfortable, a person with a choice will likely choose another mode, while a person without a choice may be greatly inconvenienced and be less likely to continue to use transit once another choice becomes available. Service delivery encompasses four main factors:[R17]

1. *Reliability*: how often service is provided when promised;
2. *Customer service*: the quality of direct contacts between passengers and agency staff and customers' overall perception of service quality;
3. *Comfort*: passengers' physical comfort as they wait for and use transit service; and
4. *Goal accomplishment*: how well an agency achieves its promised service improvement goals.

Time- and speed-related measures can be used by themselves or converted into other forms to aid in comparisons.

Travel Time

Travel time addresses the amount of time it takes to make a trip by transit and the speed that passengers travel while making their trips. Travel time values can be reported by themselves, in comparison with other modes, or in comparison with ideal values. Time can be aggregated by the number of people (e.g., person-minutes of delay) or converted into a monetary value for use in comparing the costs of two alternative trips.

Passengers' perceptions of safety and security are as important to consider as actual conditions.

Safety and Security

This category relates to the likelihood that one will be involved in an accident (*safety*) or become the victim of a crime (*security*) while using transit. Measures of safety and security are often more qualitative, as riders' perceptions of the safety and security of transit, as well as actual conditions, enter into their mode choice decision. Some "irritation" factors, such as encountering unruly passengers on a regular basis or having to listen to someone else's radio, may not show up in security-related performance measures but may contribute to a passenger's sense of unease, even if the actual risk of being involved in a crime is minimal or non-existent.

Maintenance quality has direct and indirect impacts on quality of service.

Maintenance

The quality of a transit agency's maintenance program has direct and indirect impacts on passengers' perceptions of service quality. A transit vehicle that breaks down while in service, for example, impacts passengers' travel time for that trip and their overall sense of system reliability. Having insufficient spare buses available may mean that some vehicle runs never get made, which, in turn, reduces transit service availability, increases the level of crowding on the subsequent trips, and affects passengers' perceptions of reliability. Dirty vehicles may suggest to passengers a lack of attention to less visible aspects of transit service, while graffiti, window etchings, and so forth may suggest a lack of security.

SUMMARY

This chapter showed that transit performance can be measured from a variety of points of view but that quality of service focuses on the passenger point of view. The chapter discussed the key aspects of quality of service: *availability*—is transit an option for a given trip—and *comfort and convenience*—how a transit trip compares with the same trip made by a different mode. Finally, five categories of performance measures that relate to quality of service—availability, service provision, travel time, safety and security, and maintenance—were introduced. These categories will be reviewed further in the next chapter, and specific performance measures will be identified for each category.

CHAPTER 2. QUALITY OF SERVICE FACTORS

INTRODUCTION

The previous chapter introduced broad categories of issues relating to quality of service. This chapter looks at each of these factors in much greater detail. The chapter also presents different ways of measuring performance and identifies many qualitative and quantitative performance measures that relate to quality of service. Finally, the chapter discusses the aspects of service quality that have been found generally to be the most important to passengers on a national basis and can also be relatively easily quantified. These service quality aspects were used to develop the quality of service framework presented in this manual.

AVAILABILITY FACTORS

Service Coverage

As discussed in Chapter 1, 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, or demand-responsive service will be available at one's doorstep. 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. In addition, upgrading existing facilities to meet Americans with Disabilities Act (ADA) regulations also results in a more comfortable walking environment for other transit users. When transit service is not provided near one's origin, driving to a park-and-ride lot or riding a bicycle to transit may be viable alternatives.

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

Service coverage considers both ends of a trip, for example, 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.

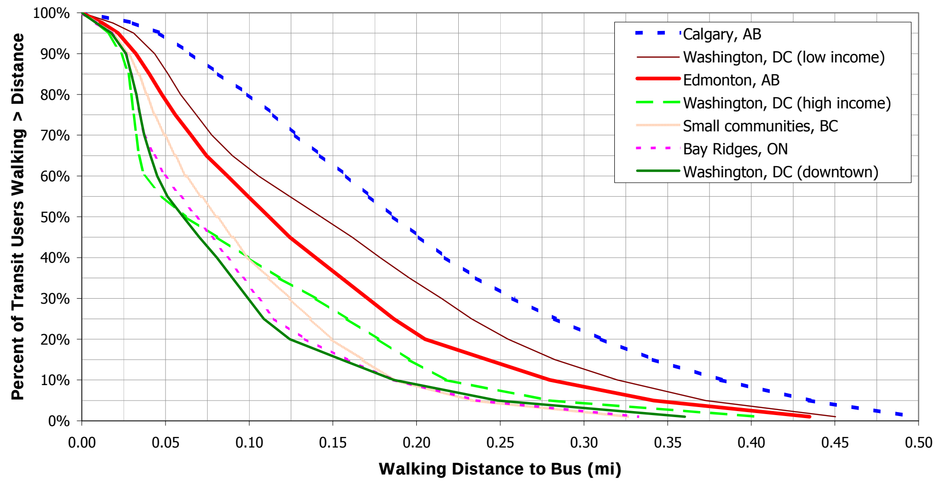
Service coverage considers both ends of a trip.

Pedestrian Access

Walking Distance to Transit

The maximum distance that people will walk to transit varies depending on the situation. Exhibit 3-5 shows the results of several studies of walking distances to transit in North American cities. 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) walk one-quarter mile (400 meters) or less to bus stops. At an average walking speed of 3 mph (5 km/h), this is equivalent to a maximum walking time of 5 minutes. These times and distances can be doubled for rail transit.[R26] Bus service that emulates rail transit—frequent service throughout much of the day, relatively long stop spacing, passenger amenities at stops, etc.—is expected to have the same walking access characteristics as rail transit (e.g., a maximum walking time of 10 minutes). However, at the time of writing, no research had yet been conducted to confirm this expectation.

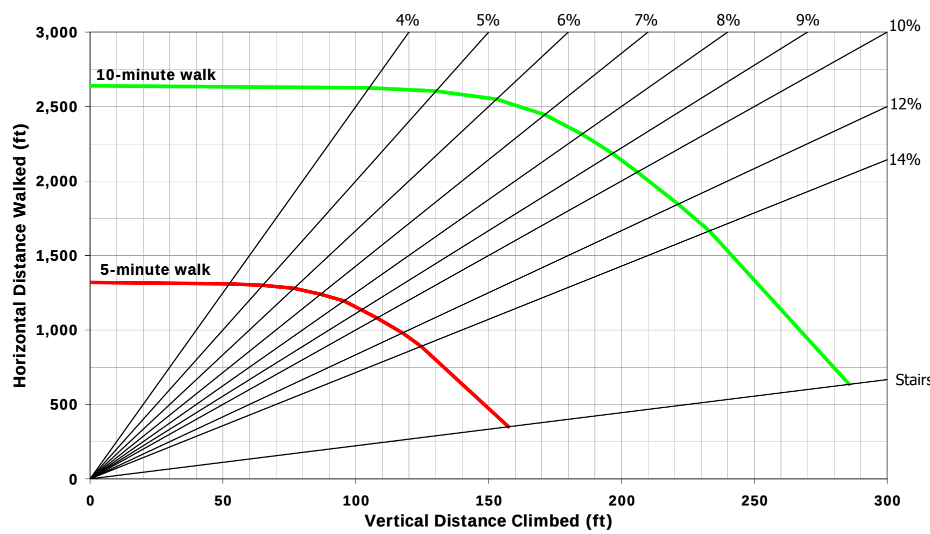
Exhibit 3-5
Walking Distance to Bus Stops(R3,R20,R29,R36)



An alternative exhibit using metric units appears in Appendix A.

Other factors can shorten the distance that people will walk to transit stops. A poor pedestrian environment, discussed below, will discourage 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 3-6 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 feet climbed for each 100 feet traveled horizontally), grades have little impact on travel speed, but that above 5%, the distance that can be traveled within 5 or 10 minutes (0.25 mi/400 m or 0.5 mi/800 m on level terrain) diminishes.

Exhibit 3-6
Effect of Grade on Distance Walked(R23)



An alternative exhibit using metric units 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. Lack of sidewalks, poorly maintained sidewalks, and lack of street lighting all discourage pedestrian travel. Wide or busy streets without safe and convenient means to cross the street also 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 the service between signalized crossing points. The difficulty pedestrians experience crossing streets can be expressed by the amount of delay they experience waiting for the WALK signal (at signalized crossings) or for a safe gap in traffic (at unsignalized crossings). Pedestrians start exhibiting risk-taking behavior (e.g., jaywalking or running across the street) when their delay exceeds 30 seconds.(R16)

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 to and from streets with transit service from 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-mile (400-meter) walking distance of a transit stop, even when the majority of the subdivision is located within a one-quarter-mile 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, curb cuts, and bus stop loading areas between their origin and a transit stop and between their destination and a transit stop in order to have the ability to access fixed-route transit service. Without these facilities, 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.

Bicycle Access

Linking bicycles and transit provides benefits to both modes of travel. Access to transit allows bicyclists to make longer trips, and to traverse barriers (such as freeways) that would otherwise eliminate cycling as an option. Transit also provides an option for bicyclists when weather turns unexpectedly bad, their headlight fails, or they find themselves too tired to make it all the way home. Improving bicycle access attracts new transit riders and expands transit's catchment area. A number of systems that have provided bicycle facilities—particularly bus-mounted bicycle racks—have found them to be popular and well-used. Lane Transit District in Eugene, Oregon, for example, averaged 700 to 800 daily bicycle boardings in 2001.

Effective links between bicycling and transit relies on three components:(R12)

- Bicycle connections to stops and stations,
- Bicycle parking at stops and stations, and
- On-vehicle bicycle-carrying facilities.

The federal match for transit enhancement grants to link bicycles and transit can be up to 95% of project cost, while non-bicycle related transit enhancement grants are limited to an 80% federal share. Some transit systems with bus-mounted bicycle racks also use the racks as advertising space that is visible when the rack is not in use.

Bicycle Trip Lengths

Typical bicycling speeds are approximately 12 to 15 mph (20 to 25 km/h), or about four to five times higher than walking speeds. This speed advantage allows transit users to access routes much farther away from their origin or destination than they could if they walked. Typical bicycle trip lengths are approximately 2 to 4 miles (3.5 to 7 km) for casual riders and 4 to 6 miles (7 to 10 km) and longer for experienced riders.[R12] Each portion of a bicycle access-to-transit trip will typically be shorter than these bicycle-only trip lengths, but even a short trip can increase the catchment area of transit stops or stations significantly. Assuming a conservative 5-minute travel time (as used for walking trips), bicycle access to a bus stop would have an approximate radius of 1 to 1.25 miles (1.6 to 2.0 km), which would increase the coverage area of a stop by up to 25 times that for walk-only trips.

Roadway Environment

Just as with pedestrian access to transit, safe and convenient facilities need to be provided to encourage bicycle access. On-street connections should allow cyclists to use bicycle-friendly streets (e.g., low-volume collector or arterial streets that have been modified for cycling) to reach transit stations. Physical modifications made to these streets should be designed based on AASHTO or other appropriate standards. These might include marked bicycle lanes, striped wide shoulder lanes, wide outside lanes, "bike route" signs, and other treatments.[R12]

Bicycle Parking

Security is the most important issue with bicycle parking at transit stops. In the United States, bicycle theft rates are about twice as high as Germany's and five times higher than Japan's. Bicycle thefts cost Americans an estimated $400 million per year.[R12]

Security concerns about enclosures that are not visible from the outside may limit potential bicycle storage options.

Secure parking for bicycles can be provided in the form of racks, lockers, or cages. These facilities should be located in highly visible and well-lit areas that are also out of the way of direct pedestrian traffic flow. Other considerations include facility design that enhances bicycle security (e.g., using only racks that accommodate high-security bicycle locks, providing security camera surveillance, etc.).

On-Vehicle Bicycle-Carrying Facilities

In 2001, more than 25% of all public transit vehicles in the United States were equipped with bicycle racks, such as the one shown in Exhibit 3-7(c).[R2] These are typically folding devices that are mounted on the front of buses and carry two bicycles. A few bus operators allow bicycles to be brought on board during off-peak times. Rail transit operators often allow bicycles aboard trains but may restrict the times of day, directions of travel, and/or locations within the train where bicycles are allowed.

Many agencies that have started a bikes-on-transit program have required users to obtain a permit. However, as agencies have gained positive experiences with bicycle passengers, and as bicycle rack designs have been simplified, some agencies have dropped their permit requirement.

Exhibit 3-7
Bicycle Facility Examples

(a) Bicycle Racks (Olympia, Washington)

(b) Bicycle Lockers (San Jose)

(c) Bus-mounted Bicycle Rack (Honolulu)

(d) Bikes on Ferry (Larkspur, California)

Park-and-Ride Access

Walking is not the primary access mode for certain types of transit services, particularly express bus and commuter rail services. For these modes, automobile access via park-and-ride lots is the primary means of passenger access. Park-and-ride lots also help support transit access in lower-density areas where fixed-route service is not economical, as it focuses transit boarding demand to a small number of points.

An Overview of the Park-and-Ride User

A number of surveys were reviewed for the Maricopa Association of Governments (MAG) to determine the characteristics of park-and-ride users in the Sacramento, Northern Virginia, Chicago, Seattle, and Phoenix areas.[R19] Key characteristics of these park-and-ride users are summarized below:

- 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%) traveled to the CBD for work more than four times per week,
- Parking at the destination was expensive,
- Convenient, frequent bus service was offered, and
- Most riders found park-and-ride facilities because they could see them from their regular commute routes.

The MAG review also lists the characteristics of a successful park-and-ride lot. Some of the key points are summarized below:[R19]

- *Location*: the literature reveals that a successful park-and-ride facility should be located at least 4 to 6 miles (7 to 10 km)—preferably 10 miles (16 km)—from a major destination.

- *Transit Service*:
  - Frequent express service (the primary demand-generating characteristic of successful park-and-ride facilities),
  - Close proximity to a freeway or light rail,
  - HOV access for at least a portion of the transit trip, and
  - Visibility from adjacent arterials.
- *Auto access to the park-and-ride facility*: access should be made as convenient and as rapid as possible. The transit portion of a patron's trip should (in most cases) represent more than 50% of the total journey time from the patron's home to final destination.(R6)
- *Auto-to-Transit Cost Ratio*: parking costs are an important element in determining the cost of auto access. The parking cost at the trip destination is typically considerably higher than the round-trip transit fare.

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 other higher occupancy vehicles (HOV or carpool modes). Park-and-ride facilities are usually classified by location or function. A hierarchy of lots can be described as follows:(R37)

- *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 parking facility with another activity such as a church, theater, shopping mall, or special events center. 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.

Park-and-ride lots can also be classified by land use, location, and/or distance from the destination. A different demand estimation technique is usually developed for each lot type:(R13,R37)

- *Peripheral lots* include facilities built at the edge of a downtown, and other intensely developed, highly congested activity centers, such as universities or auto-free zones. These lots intercept travelers prior to the activity center, storing vehicles in a location where parking costs are relatively inexpensive.
- *Local urban lots* fill the gap between the suburban market and the downtown. They lie typically between 1 to 4 miles (2 to 7 km) from the downtown and are often served only by local or local-express transit routes.

- *Urban corridor lots* are located along major commute corridors and are typically served by line-haul transit. HOV corridor lots are a subset of this category and are located adjacent to major highways that provide HOV lanes.
- *Suburban/urban fringe lots* are located 4 to 30 miles (7 to 50 km) from the downtown and provide an intermodal (change of vehicle) service. The more distant lots generally are not served by transit, although this is not universally true.
- *Remote/rural lots* are generally located outside the urban area in a rural or small-town setting. Typical distances range from 40 to 80 miles (65 to 130 km).

Park-and-Ride Market Areas

Market shed analysis relies on the definition of a service area or market shed. Theory suggests that, once a market area is defined for park-and-ride lots, socioeconomic data can be collected regarding the people living within the market shed. These data can then be used to predict demand for specific park-and-ride facilities. A number of studies have attempted to identify a single standardized market shape and size. The literature indicates that the most common market areas for park-and-ride services reflect parabolic, semicircular, or circular shapes.

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

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.

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.

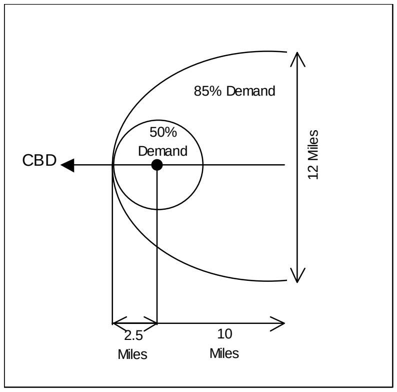
A study of Seattle-area park-and-ride lots found that for suburban lots, 50% of the park-and-ride facility's demand is typically generated within a 2.5-mile (4-km) radius of the facility, and that an additional 35% comes from an area defined by a parabola extending 10 miles (16 km) upstream of the lot and having a long chord of 10 to 12 miles (16 to 19 km).[R28] This market area is illustrated in Exhibit 3-8(a).

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.[R37] The offset circular model is illustrated in Exhibit 3-8(b).

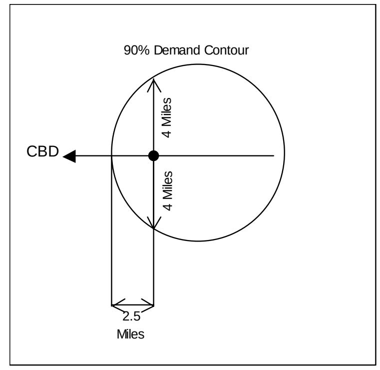
A study conducted for the North Central Texas Council of Governments found that the average market shed for "non-suburban" (i.e., peripheral) lots is typically more dispersed around a common center than the suburban park-and-ride types, as shown in Exhibit 3-8(c).[R25] These findings were confirmed in a similar study from the Puget Sound region, which examined two lots that operate as peripheral park-and-ride facilities.[R37]

Finally, simple assumptions are often used for remote lots. In Florida, approximately 50% of remote lot users live within 3 miles (5 km) of the lot and about 90% come from within 19 miles (30 km).

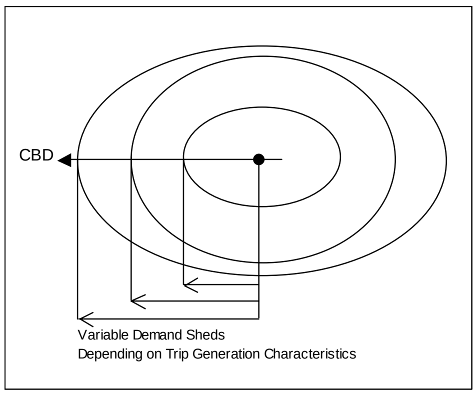
Exhibit 3-8
Example Park-and-Ride Market Areas(R25, R28, R37)



(a) Suburban Lot (Seattle)



(b) Suburban Lot (Texas)



(c) Peripheral Lot (Texas)

Scheduling

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 provided 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. As the number of hours and days that service is provided increases, the number of trip types that can be served by transit greatly increases. Providing service into the evening hours, for example, allows someone who normally uses transit to commute to work to continue to use transit on days when that person must work late or wishes to remain downtown after work for other activities.

Capacity

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 or a non-functional lift 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. However, service denials can be and are used by general public demand-responsive providers as a means of rationing capacity to control costs.

Information

Passengers need to know how to use transit service, where to go to access it, 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.

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

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 rail stations, train directions, major bus stops, fare zone boundaries, etc. 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 on-board announcements that may be muffled by other noise.
- *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;
- *Telephone information*, customized to an individual customer's needs; and
- *Internet information* available 24 hours per day to anyone with Internet access.

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 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 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 minutes, 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.

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

COMFORT AND CONVENIENCE FACTORS

Passenger Loads

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 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, and rail passengers may try to hold doors open in order to squeeze onto the train.

Most transit agencies assess the degree of passenger crowding on a transit vehicle based on the occupancy of the vehicle relative to the number of seats, expressed as a *load factor.* A factor of 1.0 means that all the seats are occupied. The importance of vehicle loading varies by the type of service. In general, transit provides load factors at or below 1.0 for long-distance commute trips and high-speed mixed-traffic operations. Inner-city rail service may approach 2.0 or even more, while other services will be in between.

Some agencies' service standards balance service frequencies with passenger loads. When boarding volumes are relatively low, service frequencies will also be low, to avoid running nearly empty buses, but sufficient buses will be provided to ensure that all passengers can have a seat. At higher boarding volumes, not all passengers will be able to get a seat, but frequencies are set high enough to ensure that passengers will not have to wait long for the next bus.

Because the number of seats provided varies greatly between otherwise identical rail vehicles operated by different transit systems, measuring loading by the number of passengers per unit vehicle length is often more appropriate for rail capacity calculations than using a load factor.

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. 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.

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 on-board announcements are given explaining the delay.

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 probability 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 they arrived at the end of the route late;
- *Evenness of passenger demand,* both between successive vehicles and from day to day for a given vehicle and run;
- *Differences in operator driving skills,*[R39] 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;
- *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;[R1,R38] and
- *Operations control strategies* used to react to reliability problems as they develop, thus minimizing the impact of the problems.[R21]

Travel Time

A longer trip by transit than by automobile may be seen by passengers as being less convenient; this may be mitigated somewhat if the on-board transit time can be used productively where the in-car time would not be.

Total trip time includes the travel time from one's origin to a transit stop, waiting time for a transit vehicle, travel time on-board a vehicle, travel time from a transit stop to one's destination, and any time required for transfers between routes during the trip. The importance of each of these factors varies from person to person. Some persons will view the trip as an opportunity for exercise during the walk to transit and for catching up on reading or work while aboard a vehicle. Other persons will compare the overall door-to-door travel time of a trip by transit with the time for the same trip by private automobile. Total trip time is influenced by a number of factors, including the route and stop spacing (affecting the distance required to walk to transit), the service frequency (affecting wait time), traffic congestion, signal timing, and the fare-collection system used (affecting travel time while on a transit vehicle).

Travel time can be measured by itself or in relation to other competing modes—for example, by the difference between auto and transit travel times or by the ratio of those two times.

Transfers

Requiring transfers can make service more efficient for operators, but can be less convenient for passengers, depending on the circumstances. Each transfer adds to a passenger's total trip time, due to the wait required between buses, although this factor can be minimized by implementing timed transfers. However, introducing a transfer into what was previously a one-seat service from origin to destination may have a net positive benefit for passengers, if the new route that the passengers transfer to offers a net time savings, service frequency improvements, or other passenger benefits over the old service.(R31)

Transfers also raise the possibility that a missed connection will occur, which would increase the length of a passenger's trip by the amount of one headway. Transfers also increase the complexity of a transit trip to first-time passengers. Requiring a surcharge for transfers can inhibit ridership.

Passenger Perceptions of Time

Passengers perceive the passage of time differently for each portion of their trip—walk time to transit, wait time at the stop, in-vehicle time, and transfer time. *TCRP Web Document 12*(R31) documents the results of a number of studies of the relative importance of travel time. Exhibit 3-9 presents these results for work trips. A value of 2, for example, indicates that one minute of a particular travel time component (e.g., wait time) is perceived by passengers as being twice as onerous as one minute of in-vehicle time.

Exhibit 3-9
Relative Importance of Travel Time Components for Work Trips(R31)

	In-vehicle Time	Walk Time	Initial Wait Time	Transfer Time
Average	1.0	2.2	2.1	2.5
Range	1.0	0.8-4.4	0.8-5.1	1.1-4.4

Some studies have also identified a transfer penalty in addition to the higher importance of transfer time relative to in-vehicle time. Reported transfer penalties are typically in the range of 12 to 17 minutes.(R31) The transfer penalty for trips with neither end at home can be very high: a study used to develop the Minneapolis-St. Paul area's mode choice model found a penalty of 27 minutes for non-home, work-based trips, and 2 hours for non-home, non-work based trips.(R27)

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 includes the potential for being involved in a crash, as well as slips and falls while negotiating stairs or other elements of the transit system. Security covers both the real and perceived chance of being the victim of a crime while using transit. It also covers irritants, such as encountering unruly passengers on a regular basis or having to listen to someone else's radio.

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.

Cost

Potential passengers weigh the cost and value of using transit versus 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.

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

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 (for example, Bay Area Rapid Transit in the San Francisco Bay Area, Housatonic Area Regional Transit in Danbury, Connecticut, the Tidewater Transportation Commission in Norfolk, Virginia, and MTA-New York City Transit) have established standards for transit facility appearance and cleanliness and have also established inspection programs.(R9,R17,R41)

TCRP Report 88(R17) provides more information on these "passenger environment survey" programs.

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.

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, rather than a necessity.

Amenities: frills or necessities?

The types of amenities provided are generally related to the number of boarding passengers at a stop. Examples of transit amenities, some of which are illustrated in Part 7, include the following:(R40)

TCRP Report 19(R40) provides guidelines for designing, locating, and installing transit amenities.

- *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, some agencies provide pushbutton-operated overhead heaters at shelters located at major transit centers.
- *Lighting,* to improve passengers' sense of security at the stop.

- *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 around the transit stop. However, because of security concerns, some agencies are choosing to remove trash receptacles.
- *Telephones,* to allow passengers to make personal calls while waiting for a transit vehicle, as well as providing for the ability to make emergency calls. Telephones should be programmed to allow outgoing calls only to discourage loitering around the stop.
- *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.

MEASURING QUALITY OF SERVICE

Quantitative Measures

Certain aspects of transit performance can be quantified—that is, expressed as a number. Numerical values, by themselves, provide no information about how "good" or "bad" a particular result is, or whether one value is particularly different from another value, from a passenger's point of view. In order to provide this interpretation, performance results can be compared with a fixed standard or with past performance. Alternatively, the results can be expressed in a format that provides built-in interpretation. Two such formats are described below.

Levels of Service

Origin of the level of service concept.

The concept of LOS was originally developed in the 1965 *Highway Capacity Manual*. Under this concept, the potential values for a particular performance measure are divided into six ranges, with each range assigned a letter grade ranging from "A" (highest quality) to "F" (lowest quality). Ideally, the threshold between each letter grade represents a point where the service quality becomes noticeably different to travelers, whether they are motorists or transit riders. Within each letter grade, travelers ideally would notice no significant difference in service quality between different performance measure results assigned to that LOS grade. In practice, the change in traveler perceptions between adjacent LOS grades is often more of a transition than a distinct step at the threshold.

The key aspects of levels of service are two-fold:

1. The LOS ranges should reflect a traveler's point-of-view. LOS "A", therefore, is not necessarily representative of optimum conditions from a transit provider's point-of-view.
2. LOS "F" should represent an undesirable condition from a traveler's point-of-view. The service provider may choose to set higher standards based on their needs or policy goals.

LOS grades should not be interpreted as being the same as school grades.

Because of their similarity to letter grades received in school, a potential danger of levels of service is that they may lead persons unfamiliar with the LOS concept to the incorrect conclusion that LOS "A" should be the target that service providers should aim for (i.e., "I wouldn't accept my child bringing home C's and D's from school; why should we accept those grades in our transit service?"). In many cases, providing too good an LOS can be just as bad as providing a poor LOS, as agency resources are diverted to unproductive service instead of being used to improve service quality in areas where improvement is really needed. What users might consider to be the best possible service quality is often uneconomical to provide, and service providers must strike a balance between service quality and affordable service. Nevertheless, LOS "F" should be considered undesirable both scholastically and in terms of transit performance.

A major reason why this manual has adopted LOS letter grades for fixed-route service is consistency with how other modes already measure quality of service. Many planning organizations (e.g., planning departments and MPOs), and decision-making bodies (e.g., city councils and boards of commissioners) are already familiar with LOS letter grades as they are applied to highways. Adopting a similar system for fixed-route transit and other modes allows all transportation modes to share a common language on how quality of service is measured, and eases the learning curve for planners and decision-makers who may be less familiar with transit operations than with roadway operations.

Fixed-route transit service uses letter grades to measure LOS.

This manual also uses the LOS concept to describe passengers' perceptions of the quality of demand-responsive service. However, demand-responsive service has fundamental differences from fixed-route service, particularly in the manner of access, degree of trip spontaneity, and flexibility in choosing origins and destinations. Thus, one cannot easily directly compare the quality of demand-responsive service with fixed-route service. Therefore, demand-responsive LOS uses a 1 to 8 numerical scale, rather than an "A" to "F" letter scale, to describe differences in passenger perceptions. Because of the great range of types of demand-responsive services, from same-day taxi-based services in urban areas to rural service provided once or twice per month, a greater number of service levels are used for demand-responsive service, in order to adequately describe differences in passenger perceptions.

Demand-responsive service uses numerical scores for LOS.

Indexes

Performance measure users can quickly become overwhelmed as the number of performance measures being tracked and reported increases. One technique to minimize the number of measures reported, while maximizing the number of quality of service factors measured, is to develop a quality of service index. Such an index can incorporate several different performance measures, and each component can be assigned a weight reflecting its relative importance. Weights would be determined locally (e.g., from the results of a survey). The typical form of an index is as follows:

$$i = c_n\left(w_1 p_1 + w_2 p_2 + \cdots + w_x p_x\right)$$

Equation 3-1

where:

i = index value;

c_n = constant to normalize the maximum index value to a particular value;

w_x = weight of performance measure x; and

p_x = value of performance measure x.

Although indexes are useful for developing an overall measure of service quality, the impact of changes in individual index components are hidden. A significant decline in one aspect of service quality, for example, could be offset by small gains in other aspects of service quality.

Indexes can simplify performance reporting, but can mask changes in individual quality factors.

Qualitative Measures

Quantitative measures assess things that are directly observable about transit service. In contrast, qualitative measures assess passengers' perceptions. The latter measures' value lies in identifying aspects of service quality that are difficult or impossible to measure directly—things such as security, staff courtesy, value for the money, and so on. One commonly used, but indirect, method of identifying customer opinions is by tracking complaints and compliments that are made. Complaint tracking is inexpensive, but has the disadvantage of being reactive—a customer has already been made so unhappy that he or she has taken the time to complain. Complaint tracking also is only useful when customers feel that their complaints are taken seriously. If passengers lose this feeling, they may stop complaining, not because the problem has gone away, but because nothing ever appears to be done about the complaints.

Two methods used by transit agencies to help identify problems before they become serious enough to generate many complaints are customer satisfaction surveys and passenger environment surveys, which are described below.

Customer Satisfaction Surveys

Customer surveys help transit operators identify the quality of service factors of greatest importance to their customers. They can also be used to help prioritize future quality of service improvement initiatives, measure the degree of success of past initiatives, and track changes in service quality over time. Surveys can identify not only areas of existing passenger satisfaction or dissatisfaction, but the degree to which particular factors influence customer satisfaction. Thus, these surveys can help identify the quality of service factors of greatest importance to the riders of a particular transit system. Exhibit 3-10 shows examples of service attributes that could be rated as part of a customer satisfaction survey, with each attribute rated on a 1 to 5 or 1 to 10 scale, for instance.

TCRP Report 47[R22] identifies a "impact score" process that transit operators can use to identify the most important quality of service factors for their passengers, based on the results of a customer satisfaction survey. First, a *gap score* is developed for each service attribute, consisting of the difference between the average rating for the attribute among those who did not experience a problem with that attribute during the previous 30 days and the average rating among those who did experience a problem. The greater the gap score, the more important that a problem with that attribute is to passengers.

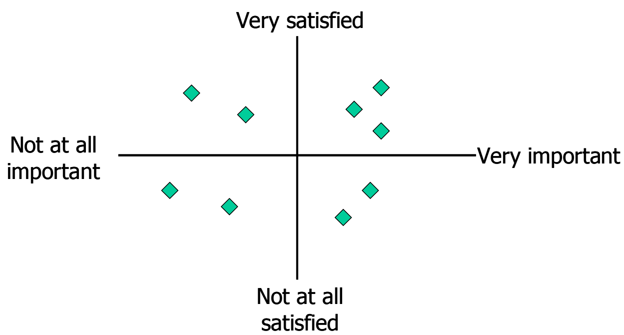
Exhibit 3-10
Examples of Transit Service Attributes[R22]

Absence of graffiti	Frequency of service on Saturdays/Sundays
Absence of offensive odors	Frequent service so that wait times are short
Accessibility to persons with disabilities	Friendly, courteous, quick service from personnel
Availability of handrails or grab bars	Having station/stop near one's destination
Availability of monthly discount passes	Having station/stop near one's home
Availability of schedule information	Hours of service during weekdays
Availability of schedules/maps at stops	Number of transfer points outside downtown
Availability of seats on train/bus	Physical condition of stations/stops
Availability of shelter and benches at stops	Physical condition of vehicles and infrastructure
Cleanliness of interior, seats, windows	Posted minutes to next train/bus at stations/stops
Cleanliness of stations/stops	Quietness of the vehicles and system
Cleanliness of train/bus exterior	Reliable trains/buses that come on schedule
Clear and timely announcements of stops	Route/direction information visible on trains/buses
Comfort of seats on train/bus	Safe and competent drivers/conductors
Connecting bus service to main bus stops	Safety from crime at stations/stops
Cost effectiveness, affordability, and value	Safety from crime on trains/buses
Cost of making transfers	Short wait time for transfers
Display of customer service number	Signs/information in Spanish as well as English
Ease of opening doors when getting on/off	Smoothness of ride and stops
Ease of paying fare, purchasing tokens	Station/stop names visible from train/bus
Explanations and announcements of delays	Temperature on train/bus—not hot/cold
Fairness/consistency of fare structure	The train/bus traveling at a safe speed
Freedom from nuisance behaviors of riders	Trains/buses that are not overcrowded
Frequency of delays from breakdowns/ emergencies	Transit personnel who know system

Second, an *occurrence rate* for each service attribute reflects the percentage of survey respondents who experienced a problem with that attribute during the previous 30 days. The higher the occurrence rate, the greater the number of passengers that experience problems with that service attribute. Finally, an *impact score* is calculated that multiplies the gap score by the occurrence rate. The higher an attribute's impact score, the greater the impact that changes in this attribute's quality will have on overall customer satisfaction. Attributes can be sorted by impact score to develop a prioritized list of service quality factors requiring attention.

An alternative way to look at customer satisfaction survey results is through *quadrant analysis.* Service attributes can be plotted on a chart similar to the one shown in Exhibit 3-11, with the customer-rated importance of an attribute plotted against the customer-rated satisfaction with that attribute. Attributes with the greatest impact on customer satisfaction will appear in the lower-right quadrant, while those with the least impact will appear in the upper-left quadrant.

Exhibit 3-11
Customer Satisfaction Quadrant Analysis(R22)



A full description of how to perform a customer satisfaction survey and use the results of such a survey is beyond the scope of this manual. However, *TCRP Report 47* provides detailed information on this topic.(R22)

See *TCRP Report 47* for more information on customer satisfaction surveys.

Passenger Environment Surveys

Passenger environment surveys use a "secret shopper" technique, in which trained checkers travel through the transit system, rating a variety of trip attributes in order to provide a quantitative evaluation of factors that passengers would think of qualitatively.(R17) For example, BART rates the interior cleanliness of train cars on a 0 (lowest) to 7 (highest) scale. Points are deducted for each incidence of small litter (smaller than a 3-by-5-inch or 76-by-127-mm card), large litter, food, broken glass, spills, and biohazards, with different point values applying to each category.(R41)

Factors evaluated by MTA-New York City Transit for buses and rail vehicles include(R17)

- *Cleanliness and Appearance*—amount of litter; exterior dirt conditions; floor and seat cleanliness; graffiti; and window condition;
- *Customer Information*—readable and correct vehicle signage; presence of priority seating stickers (bus); correct and legible maps; correct and adequate bus stop signage; and audible, understandable, and accurate public address announcements;
- *Equipment*—climate control conditions; operative kneeling feature, wheelchair lift, windows, and rear door (bus); or door panel condition and lighting (rail); and
- *Operators*—proper uniforming; proper display of badges and proper use of kneeling feature (bus).

Factors evaluated by MTA-New York City Transit for rail stations include[R17]

- *Cleanliness and Appearance*—amount of litter; station floor and seat cleanliness; and graffiti;
- *Customer Information*—readable and correct signage; correct and legible maps; and audible, understandable, and accurate public address announcements;
- *Equipment*—functional speakers in stations; escalators/elevators in operation; public telephones in working order; station control areas that have a working booth microphone; trash receptacles usable in stations; functional token/MetroCard vending machines; and functional turnstiles; and
- *Station Agents*—proper uniforming and proper display of badges.

Additional information on preparing and conducting passenger environment surveys can be found in *TCRP Report 88*.[R17]

QUALITY OF SERVICE FRAMEWORK DEVELOPMENT

Service Measure Selection

Given the large number of passenger-focused performance measures to choose from, careful consideration was given to identifying a selection of measures that best fit the following criteria:

- Measures that best represented the passenger point-of-view,
- Measures that could be easily quantified in terms of levels of service, and
- Measures that were already being used by a number of agencies.

Customer Satisfaction Survey Results

TCRP Project B-11, "Customer-Defined Service Quality"[R22] developed a system for transit operators to identify the most important customer-service issues affecting their system. As part of this project, pilot tests of the project's customer satisfaction surveying techniques helped to identify some of the factors important to transit riders, regardless of the individual agency.

The project selected an urban rail system, a suburban bus system, and a small city bus system for its pilot tests, and distributed more than 13,000 surveys, with response rates ranging from 33.6% to 46.3%. The project also conducted a sampling of follow-up phone surveys. The surveys asked riders to rate 46 transit system attributes on a scale of 1 to 10 and to identify whether they had experienced a problem with that attribute within the last 30 days.

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. When analyzing the top 10 attributes that were existing problems, scheduling was the top area of concern, followed by comfort and nuisances. However, when potential problems were analyzed, fares and scheduling were the top concern, followed by comfort and safety, with nuisances the category with the least potential for high levels of concern.

The Florida Department of Transportation (FDOT) commissioned a survey of customer satisfaction factors for six larger Florida transit systems.[R8] 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.

Transit System Size Considerations

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

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

LOS ranges are not adjusted based on city size.

LOS ranges are not adjusted to reflect differences in city sizes. From an agency's standpoint, though, there are significant differences between small towns and large cities, particularly in passenger demand volumes and available funding levels. If agencies choose to develop service standards based on levels of service, these will likely vary based on community size: a small city agency might wish to provide a seat for every passenger (LOS "C" or better), while a large city agency might allow maximum schedule loads (LOS "E") during peak periods. The service measure and the quality perceived by the passenger for a given LOS is the same in both cases.

The TCQSM does not set national standards.

The TCQSM is not intended to set a national standard on the amount or level of service that should be provided for a given situation. Decisions of this nature are left to the judgment of local agencies, based on community and agency goals and objectives, development and demographic patterns, and available agency resources. The procedures given in Chapter 3 are intended to be tools that agencies can use to evaluate the service they provide or might wish to provide.

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CHAPTER 3. FIXED-ROUTE TRANSIT SERVICE MEASURES

INTRODUCTION

This chapter presents transit quality of service measures of transit availability and comfort and convenience for fixed-route service provided at transit stops, along route segments and corridors, and throughout a system. The chapter also presents other performance measures that transit operators and planners may want to consider for specific applications. Although each combination of quality of service category and transit system elements has only one service measure, analysts may find it useful to present measures in the form of a transit "report card" to better compare a number of quality of service aspects of various alternatives.

Because route segments contain a series of stops, both stop-level and route-level measures are appropriate to use for routes.

Because of the significant differences in how fixed-route and demand-responsive services operate, and how passengers perceive service quality, separate LOS measures and grading systems are provided for demand-responsive service. These are discussed in Chapter 4. Deviated fixed-route service can be evaluated using the procedures described in this chapter for fixed-route service.

AVAILABILITY—TRANSIT STOPS

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

The service measure used is *average headway,* which is the inverse of the average frequency. For convenience, Exhibit 3-12 lists LOS by both headway and frequency. Although headways are given as continuous ranges for the purposes of determining LOS, passengers find it easier to understand schedules when *clock headways* are used (i.e., headways are evenly divisible into 60), particularly when headways are long. When headways are short, clock headways are less important, as customers know that a transit vehicle will arrive soon. Also, delays due to traffic congestion at certain times of the day may require different scheduled travel times for particular trips, in which case clock headways could not be maintained at all timepoints for those trips.

When clock headways are used, vehicles arrive at the same time each hour.

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

Calculating an effective headway accounting for pass-ups.

At some locations, pass-ups may be a regular occurrence, particularly for lower-capacity services unable to accommodate peaks in demand, such as some auto ferries, or transit services following special events. In these situations, some or all passengers must wait longer than the scheduled headway before they reach the head of the line and can board a vehicle. To calculate service frequency LOS in this situation, use an effective headway calculated by multiplying the scheduled headway by the number of transit vehicles that arrive before an average passenger can board. For example, if half the peak hour passengers, on average, must wait for a second vehicle, the effective headway would be 1.5 times the scheduled headway.

Exhibit 3-12
Fixed-Route Service Frequency LOS

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

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

Other Measures

Other measures that may be important to consider at the transit stop level include those listed below. Further information about these and other measures can be found in *TCRP Report 88*[R17] and in the references identified with specific measures in the following list:

- *Pedestrian crossing difficulty* can be quantified by crossing delay, using the equations given later in the service coverage LOS section.
- *Pedestrian access* can be measured by the pedestrian LOS in the vicinity of the stop. For example, the Florida Department of Transportation uses a pedestrian LOS that accounts for traffic volumes, pedestrian facility type, amount of separation between pedestrians and traffic, and other related factors.[R14]
- *Bicycle access* can be measured by the bicycle LOS in the vicinity of the stop. Researchers[R14,R15] have developed LOS measures that account for traffic volumes, amount of separation between bicycles and traffic, and other related factors.
- For stops associated with a park-and-ride lot, *park-and-ride access* can be measured by the lot occupancy (number of parking spaces occupied, divided by the total number of spaces in the lot). At an occupancy of 95% or higher, the lot is effectively full and unable to serve additional potential passengers.
- *Access for persons with disabilities* can be quantified by examining the stop vicinity (e.g., landing pads, sidewalk widths and condition, grades, curb cuts, etc.) for compliance with the ADA. For example, a stop could be classified as fully, partially, or non-accessible, depending on whether all, most, or only some of the features of the stop vicinity meet the ADA guidelines. ADA access should also consider how frequently ADA-accessible vehicles serve the stop, and—for stations not at-grade—the percentage of time that station elevators are out of service.
- *Passenger loading* affects availability when passengers are unable to board the first vehicle that arrives, due to overcrowding. The passenger loading LOS measures presented later in this chapter can be used—LOS "F" indicates crush loads where additional passengers would be unlikely to board.

AVAILABILITY—ROUTE SEGMENTS/CORRIDORS

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

"Service span" is a commonly used synonym for hours of service. However, it is measured as the time between the first and last trips of the day, without regard to any gaps in service during that time.

Hours of service LOS (Exhibit 3-13) is based only on those hours when service is offered at essentially a minimum 1-hour frequency (i.e., service frequency LOS "E" or better). Judgment should be applied to situations where the scheduled headway is slightly longer than 1 hour, due to differences in scheduled departure times as a result of traffic congestion or other factors. For example, a 65-minute headway between two trips can be considered essentially 1-hour service, if the previous and subsequent trips operate at 60-minute or better headways, while a 90-minute service gap to provide an operator lunch break would not be considered hourly service.

In contrast, hours of service are only counted when service is offered essentially hourly or better.

Hours of service can be measured at a given location, or for a particular trip. It may be more appropriate to measure hours of service by trip than by route. For example, an express bus route may operate peak hours only between a park-and-ride lot and the CBD. During off-peak midday hours, the trip might still be possible using a less frequent, slower local bus route. If measured by route, the express service would end up with a low LOS, due to the small number of hours it operates. From a passenger's perspective, though, a trip could be made whenever either the express or local service operates, and hours of service in this case would be best calculated using the combination of the express and local service spans. The differences in service quality between the two routes could be measured by assessing frequency and transit-auto travel time LOS for the same trip during peak and midday periods.

Measuring hours of service for peak hour services.

To calculate hours of service, when service is offered at least hourly without interruption, subtract the departure time of the last run from the departure time of the first run and add 1 hour. This additional hour accounts for the last hour when service is provided (for example, trips at 6:00 a.m. and 7:00 a.m. provide service during 2 hours of the day, even though 6:00 subtracted from 7:00 is one). Round down any fractional hours. When service is not operated at least hourly throughout the day, calculate the number of hours of service for each portion of the day when service is provided, and then use the total in determining the LOS.

Exhibit 3-13
Fixed-Route Hours of Service LOS

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

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

Example Calculations

Peak hour service only. A bus route operates peak hours only, *with no alternative service available at other times.* Trips are provided in each direction at 6:30 a.m., 7:30 a.m., 4:30 p.m. and 5:30 p.m. Service is provided during 2 hours in the morning and 2 hours in the evening, for a total of 4 hours. If service was provided in the peak direction only at the times given, the total hours of service for each direction would be two.

Limited daytime service. A bus route operates hourly between 5:30 a.m. and 8:30 a.m., every 2 hours between 8:30 a.m. and 4:30 p.m., and hourly between 4:30 p.m. and 7:30 p.m. The total hours of service is eight: 8:30 minus 5:30 is 3 hours and add 1 hour; 7:30 minus 4:30 is 3 hours and add 1 hour; the total is 8 hours. Although the bus route operates during the middle of the day, it does not operate at a minimum 1-hour frequency; therefore, this time is not counted.

Early evening service. A bus route operates every 30 minutes between 5:30 a.m. and 8:00 p.m. The total hours of service is 15 (20:00 minus 5:30 is 14.5, add 1 hour, and discard the fractional hour).

Other Measures

The same supplemental measures listed above for transit stops can also be applied to route segments and corridors. Pedestrian and bicycle LOS can be measured by an average LOS weighted by distance. ADA access can be measured in terms of the percentage of stops that are fully accessible, while passenger loading can look at the percentage of stops where pass-ups may occur (i.e., stops with LOS "F" for passenger loading) or the amount of time or distance a particular loading condition occurs.

AVAILABILITY—SYSTEM

Planning Methodology

Introduction

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

Service coverage LOS requires more data than the other two availability measures.

Since it is an area-wide measure, service coverage LOS takes more time to calculate and requires more information than do the transit stop and route segment/corridor LOS measures. This task can be simplified through the use of a geographic information system (GIS). However, this section also provides a calculation method that does not require GIS software. Both a planning methodology suitable for system-wide analysis and a more detailed methodology suitable for smaller area analysis are provided.

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

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

As a compromise, service coverage LOS looks at how much of the area that would typically produce the majority of a system's ridership—that is, the densest areas—are served. Specifically, those areas that may be capable of supporting hourly transit service are addressed.

Service coverage LOS looks at how much of the area likely to produce riders is served.

Service Coverage Area

The planning methodology defines the area covered by a particular route as that area within walking distance of a transit stop. This area is defined as the air distance within 0.25 mile (400 m) of a bus stop or 0.5 mile (800 m) of a busway or rail station. Any location within 0.25 mile (400 m) of the area served by deviated fixed-route bus service is also considered to be covered.

The calculation of the transit service coverage area can be performed relatively easily by GIS software, using the software's buffering feature to draw appropriately sized circles around transit stops. However, if GIS software or accurate bus stop data are not available, this area can be approximated by outlining on a map all of the area within 0.25 mile (400 m) of a bus route. This approximation assumes reasonable bus stop spacings (at least six per mile or four per kilometer). Sections of a route where pedestrian access from the area adjacent to the route is not possible (because of a barrier such as a wall, waterway, roadway, or railroad) should not be included in the service coverage area.

Transit-Supportive Areas

Pushkarev and Zupan(R32) suggest that a household density of 4.5 units per net acre (11 units per net hectare) is a typical minimum residential density for hourly transit service to be feasible. This equates to a density of approximately 3 units per gross acre (7.5 units per gross hectare). (Net acres are often referenced in zoning codes and consider only the area developed for housing or employment. Gross acres are total land areas, which may include streets, parks, water features, and other land not used directly for residential or employment-related development. Gross acres are easier to work with in calculations and therefore are used in this methodology.) Hourly service corresponds to the minimum LOS "E" value for service frequency as well as the minimum frequency used for determining hours of service LOS.

Net acres and gross acres compared.

A TriMet long-range service planning study(R24) found that an employment density of approximately 4 jobs per gross acre (10 jobs per gross hectare) produced the same level of ridership as a household density of 3 units per gross acre (7.5 units per gross hectare). These density values are used in this methodology as the minimum job densities that are capable of supporting hourly transit service.

"Jobs" refers to jobs at worksites.

Areas with a minimum density capable of supporting hourly service are referred to as *transit-supportive areas* in this methodology. For policy reasons, or simply to provide a route connecting two higher-density areas, an agency may choose to—and likely will—cover a larger area than that defined by its transit-supportive areas. However, service coverage LOS is based solely on the percentage of the transit-supportive area covered by transit, as shown in Exhibit 3-14.

Transit-supportive areas.

Exhibit 3-14
Fixed-Route Service Coverage LOS

LOS	% TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins & destinations served
B	80.0-89.9%	Most major origins & destinations served
C	70.0-79.9%	About ¾ of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least ½ of the higher-density areas served
F	<50.0%	Less than ½ of higher-density areas served

Transit-Supportive Area (TSA): The portion of the area being analyzed that has a household density of at least 3 units per gross acre (7.5 units per gross hectare) or an employment density of at least 4 jobs per gross acre (10 jobs per gross hectare).

Covered Area: The area within 0.25 mile (400 m) of local bus service or 0.5 mile (800 m) of a busway or rail station, where pedestrian connections to transit are available from the surrounding area.

TSAs reflect areas that, from a passenger point-of-view, could reasonably have transit service. Agencies that emphasize productivity over access may choose not to serve some areas considered transit-supportive by this methodology.

Service coverage is an all-or-nothing issue for transit riders—either service is available for a particular trip or it is not. As a result, there is no direct correlation between service coverage LOS and what a passenger would experience for a given trip. Rather, service coverage LOS reflects the number of potential trip origins and destinations available to potential passengers. At LOS "A," 90% or more of the TSA has transit service; at LOS "F," less than half of the TSA has service.

Deviating service to increase service coverage results in longer passenger travel times.

This measure is not intended to encourage transit operators to deviate routes substantially simply to cover more area (and thus improve service coverage LOS); should they do so, transit-auto travel time LOS will be negatively affected.

Assessing population and job coverage separately may be worthwhile for some analyses.

For some applications, it may be worthwhile to analyze service coverage LOS separately for residential population (based on only those TSAs that meet the population criterion) and employment (based on the TSAs that meet the employment criterion). This kind of analysis could help identify disconnects in the amount of service provided to potential trip origins compared with potential trip destinations.

Example Calculation—GIS Method

TriMet is the transit service provider for Portland, Oregon, and many of its suburbs. This example shows how to calculate service coverage LOS for TriMet using the planning methodology in GIS.

Data Needs

The following data are used for this calculation:

- Bus stop and light rail station locations from the regional government's GIS database and
- Transportation analysis zone (TAZ) data (households, jobs, and TAZ boundaries) from the regional transportation planning model. Alternatively, census blocks or similar relatively small areas could also have been used.

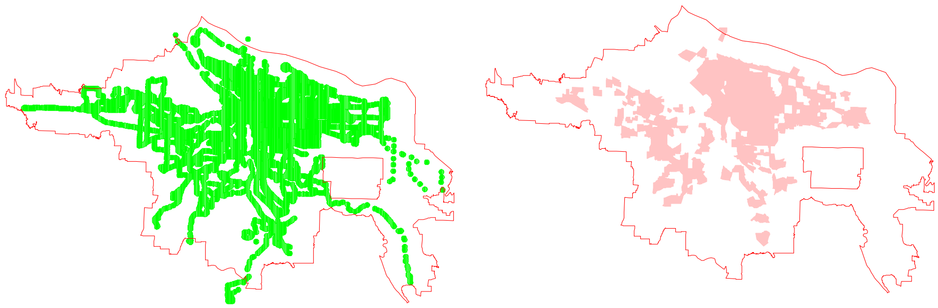
Determine Coverage Area

All of the bus stops are buffered using a 0.25-mile (400-m) radius and all of the light rail stations are buffered using a 0.5-mile (800-m) radius. Inaccessible areas are removed. The resulting 2001-2002 service coverage area is shown in Exhibit 3-15(a) and compared to the TriMet district boundary.

Determine Transit-Supportive Areas

For each TAZ, the number of households is divided by the TAZ area to obtain a household density in households per acre. Each TAZ's job density can be calculated similarly. Following these calculations, TAZs with a household density of 3.0 or more households per acre and/or a job density of 4.0 or more jobs per acre can be readily identified. These TAZs are shown as shaded areas in Exhibit 3-15(b).

Exhibit 3-15
Transit-Supportive Area Compared with Service Area



(a) District Boundary and Areas Served (b) District Boundary and Transit-Supportive Areas

Compare Service Coverage to Transit-Supportive Areas

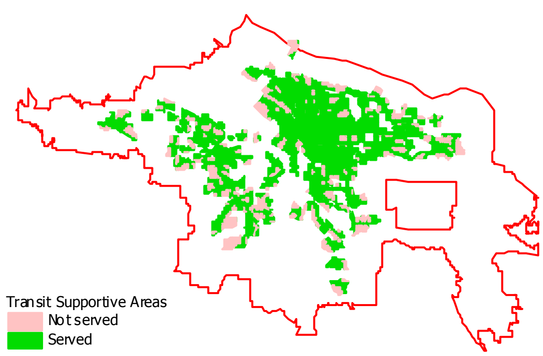
By intersecting the service coverage layer with the TAZ layer, TAZs that are only partially served by transit are divided into two sections: a section completely served by transit and a section completely unserved by transit. Households and jobs can be allocated between the two sections based on the relative areas of the two sections.

Next, all of the transit-supportive TAZs can be selected, and their total area determined, using the GIS software's area calculation function. Finally, all of the transit-supportive TAZ sections served by transit can be selected and their areas added up. Dividing the second area into the first area gives the percentage of the TSA served. Exhibit 3-16 presents numerical results; Exhibit 3-17 compares TriMet's coverage area to its TSA in the form of a map.

Exhibit 3-16
Service Coverage Results

Analysis Area	Area (mi^2)	Households	Jobs	% Area Served	LOS
TriMet District	563.8	458,076	786,713		
Coverage Area	243.1	345,260	664,684		
Transit-Supportive Area	132.9	273,341	639,375		
TSA Served	114.4	244,587	588,072	86.1%	B

Exhibit 3-17
Transit-Supportive Areas Served



How to calculate service coverage LOS without GIS software.

Example Calculation—Manual Method

Required Data

The items listed below are required for calculating service coverage manually:

- A printed map (to scale) of the TAZs, census blocks, or other area type for which household and job data are available, that cover the area being analyzed. The remainder of this example assumes that TAZs are being used from a local regional transportation model.
- Data on the number of households and jobs within each TAZ, in either printed or spreadsheet form.
- A map showing bus routes and busway and rail stations.

Estimate TAZ Areas

A transparent overlay with a printed grid helps in estimating areas. Alternatively, if the TAZ map is available electronically, the software used to develop the map may be able to calculate the area of each TAZ.

Identify Transit-Supportive Areas

Using a computer spreadsheet, or by hand, calculate household and job densities by dividing the number of households and jobs in each TAZ by the TAZ areas estimated. Areas should be converted to hectares or acres as part of this calculation.

Next, identify all TAZs where the household density is at least 3 units/gross acre (7.5 units/gross hectare) or the job density is at least 4 jobs/gross acre (10 jobs/gross hectare). Mark these TAZs on the map.

Identify the Transit Service Area

On the printed map, outline the areas within 0.25 mile (400 m) of bus routes that serve or pass near the transit-supportive TAZs and the areas within 0.5 mile (800 m) of transitway or rail stations within or near the transit-supportive TAZs. The entire system does not need to be outlined, only the portions within and near transit-supportive TAZs. Estimate the percentage (to the nearest 10%) of each transit-supportive TAZ that is covered by transit. Do not include any areas that do not have transit access due to a barrier that blocks pedestrian access, such as a freeway, railroad track, waterway, or wall.

Calculate Level of Service

Add up the areas of the transit-supportive TAZs, using the information developed earlier. This is the total area of the TSA. Next, for each transit-supportive TAZ, multiply its area by the percentage of its area served by transit. The sum of these adjusted areas is the total TSA covered by transit. Finally, divide this result by the total TSA to determine the percentage of the TSA covered by transit. Use Exhibit 3-14 to determine the LOS based on this percentage.

Detailed Methodology

Introduction

Service coverage factors not covered by the planning methodology.

The planning methodology represents a trade-off between ease of calculation and the number of factors included in the calculation. The detailed methodology addresses the following factors that the planning methodology does not address:

- The planning method's use of air distances overestimates the number of people within walking distance of transit service; a lack of pedestrian connectivity, due to topographic barriers or automobile-oriented land use development, reduces an area's access to transit;
- The effect of grades on walking distances is addressed;
- The proportion of older adults in the population, who will generally not walk as far as younger adults, is addressed;
- Transit stop accessibility is addressed (in particular, the difficulty of crossing the street with transit service).

The detailed methodology does not address the following issues. However, means for addressing the first two issues are described in subsequent sections.

- The use of a TSA does not address the extent of service provided to lower-density areas and the number of people that might be provided service in those areas;
- The service coverage provided by park-and-ride lots is not addressed; and
- Other factors than density, such as income, car ownership, and parking costs, also influence transit ridership.

The general analysis procedure is similar to the planning methodology. However, instead of using a set service coverage radius for every stop, each stop's service area is reduced in proportion to the additional time required to climb hills, cross busy streets, wind one's way out of a subdivision, and so on. Each stop ends up with an individual service radius that, in most cases, is smaller than the maximum 0.25 to 0.5 mile (400 to 800 m), and therefore serves a smaller number of people and jobs. This can be expressed mathematically as shown in Equation 3-2:

Equation 3-2

$$r = r_0 f_{sc} f_g f_{pop} f_{px}$$

where:

r	=	transit stop service radius (mi, m);
r_0	=	ideal transit stop service radius (mi, m),
	=	0.25 mi (400 m) for bus stops, and 0.5 mi (800 m) for busway and rail stations;
f_{sc}	=	street connectivity factor;
f_g	=	grade factor;
f_{pop}	=	population factor; and
f_{px}	=	pedestrian crossing factor.

Because the planning and detailed methodologies will produce different results, only one methodology should be applied within a given study area.

Because of the number of factors involved in the detailed methodology, this methodology is best suited for analyzing small areas ranging from the vicinity of an individual stop to a neighborhood. If larger areas, up to the entire system, are desired to be analyzed, developing default values (e.g., a default hourly vehicle volume for an arterial street) for many of the factors is recommended. If the detailed methodology is used, it should be applied consistently throughout the area and not mixed with the planning methodology.

Street Connectivity Factor

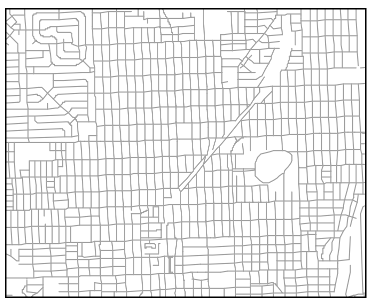
This factor reduces a stop's service coverage area in relation to the amount of out-of-direction travel a pedestrian is forced to make to get to a transit stop from the surrounding land uses. In a traditional grid street layout system, there is very little out-of-direction walking required, whereas in a contemporary suburban neighborhood with limited entry points and dead-end streets, a transit stop located only 650 feet (200 m) away in a straight line might be a 15-minute walk away using the subdivision's street system.

Three types of street patterns are defined:(R11)

- *Type 1,* a traditional grid system;
- *Type 2,* a hybrid layout that incorporates elements of both Type 1 and Type 3 street patterns; and
- *Type 3,* a cul-de-sac based street network with limited connectivity.

Exhibit 3-18 illustrates the three types of street patterns. These sketches may be used to estimate the area type surrounding the bus stops under study.

Exhibit 3-18
Street Pattern Types



(a) Type 1—Grid

(b) Type 2—Hybrid

(c) Type 3—Cul-de-Sac

As can be seen from the above sketches, a grid street pattern provides the most direct pedestrian access to transit stops. However, walking distances to and from a transit stop can still be about 42% longer than the corresponding air distance. Stated another way, only about 64% of the area within 0.25-mile (400-m) air distance of a transit stop in a grid street pattern lies within 0.25-mile walking distance of the stop. The amount of coverage provided by the other street patterns is even lower: 54% of the area within a 0.25-mile radius of a transit stop in an average hybrid street pattern lies within 0.25-mile walking distance, and only 28% of the area in an average cul-de-sac street pattern lies within 0.25-mile walking distance.

Using the grid street pattern as the best case, Exhibit 3-19 provides street connectivity factors for the other street patterns. The factor is based on the ratio of each street pattern's area covered to the area covered in a grid network.

Exhibit 3-19
Street Connectivity Factors

Street Pattern Type	Street Connectivity Factor, f_{sc}
Type 1—Grid	1.00
Type 2—Hybrid	0.85
Type 3—Cul-de-Sac	0.45

Using a network connectivity index to determine the street pattern type.

As an alternative to using the sketches, a measure of the network connectivity may be used instead to determine the area type. The *network connectivity index* is the number of links (i.e., street segments between intersections) divided by the number of nodes (i.e., intersections) in a roadway system.(R11) It is assumed for this application that all of the roadways provide for safe pedestrian travel. The index value ranges from about 1.7 for a well-connected grid pattern to approximately 1.2 for a cul-de-sac based suburban pattern. Exhibit 3-20 shows the relationship between the network connectivity index and the street pattern type.

Exhibit 3-20
Relationship Between Network Connectivity Index and Street Pattern Type

Network Connectivity Index	Street Pattern Type
>1.55	Type 1—Grid
1.30-1.55	Type 2—Hybrid
<1.30	Type 3—Cul-de-sac

Grade Factor

As shown in Chapter 1, the horizontal distance that pedestrians are able to travel in a given period of time decreases as the vertical distance climbed increases, particularly when the grade exceeds 5%. The area located within a given walking time of a transit stop decreases in proportion to the square of the reduced horizontal distanced traveled. Based on Exhibit 3-6, Exhibit 3-21 gives reduction factors for the effect of average grades on a given stop's service coverage area.

Exhibit 3-21
Grade Factor

Average Grade	Grade Factor, f_g
0-5%	1.00
6-8%	0.95
9-11%	0.80
12-15%	0.65

This factor assumes that pedestrians will have to walk uphill either coming or going. If the transit route network provides service on parallel streets, such that a person could walk downhill to one route on an outbound trip and downhill from another route back to one's origin on the return trip, use a grade factor of 1.00.

Population Factor

Pedestrian walking speed is highly dependent on the proportion of elderly pedestrians (65 years or older) in the walking population.(R16) The average walking speed of a younger adult is 4.0 ft/s (1.2 m/s), but when elderly pedestrians constitute 20% or more of the pedestrian population, a 3.3 ft/s (1.0 m/s) average speed should be used. For transit stops where 20% or more of the boarding volume consists of elderly pedestrians, a population factor, f_{pop}, of 0.85 should be used to account for the reduced distance traveled during a 5-minute walk.

Pedestrian Crossing Factor

As discussed in Chapter 1, wide, busy streets pose a barrier to pedestrian access to transit stops. The *Highway Capacity Manual*(R16) identifies that pedestrians start to become impatient once pedestrian crossing delay exceeds 30 seconds. Any crossing delay in excess of 30 seconds results in added travel time to reach a transit stop, in addition to the actual walking time. Assuming that the maximum desired travel time is fixed at 5 or 10 minutes (i.e., 0.25 or 0.5 miles, or 400 or 800 meters), excess crossing delay results in shorter maximum walking distances and a reduction in the size of a stop's service coverage area.(R18)

The pedestrian crossing factor reduces transit availability in proportion to the number of people who walk—for example—4 minutes or less to a transit stop, compared to those who walk 5 minutes or less. Using the Edmonton, Alberta, curve from Exhibit 3-5 (representing the approximate mid-point of the reported results), about 85% of transit users walk no more than 0.25 mile (400 m) to access transit, while about 75% of transit users walk no more than 1,000 feet (300 m) to access transit. If excess crossing delays amounted to the time required to walk 320 feet (100 m), then the stop's service area (assumed to be proportional to the number of people served) would be effectively reduced by a factor of 75% divided by 85%, or 0.88.(R18) Taking the square root of this result, in this case 0.94, provides the walking distance reduction that results in that reduced service area.

A best-fit curve was applied to the Edmonton data to develop the following equation for a distance-based pedestrian crossing factor:(R18)

Equation 3-3

$$f_{px} = \sqrt{\left(-0.0005d_{ec}^2 - 0.1157d_{ec} + 100\right)/100}$$

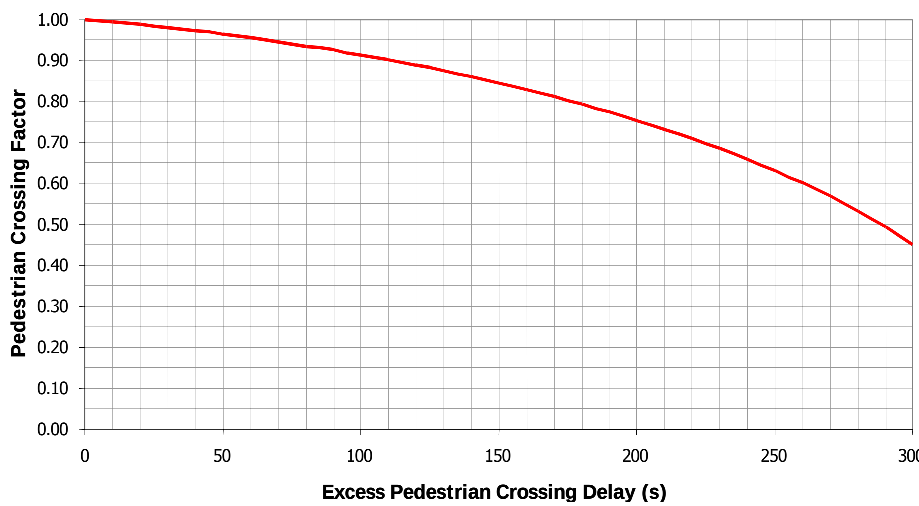
where:

f_{px} = pedestrian crossing factor; and

d_{ec} = pedestrian crossing delay exceeding 30 seconds (s).

Exhibit 3-22 depicts this curve. The factor is 1.00 whenever pedestrian crossing delay on the street with transit service is less than or equal to 30 seconds.

Exhibit 3-22
Pedestrian Crossing Factor



Calculating Pedestrian Crossing Delay

Signalized crossings. At signalized pedestrian crossings, average crossing delay is based on the cycle length and the amount of time available for pedestrians to begin crossing the street, as shown in the following equation:(R16)

Equation 3-4

$$d_p = \frac{0.5(C - g)^2}{C}$$

where:

d_p = average pedestrian delay (s);
C = traffic signal cycle length (s); and
g = effective green time for pedestrians (WALK time + 4 s of flashing DON'T WALK) (s).

Exhibit 3-23 shows typical delays incurred by pedestrians when crossing streets at signalized locations, for various street widths and median types.

Exhibit 3-23
Average Pedestrian Street Crossing Delay: Signalized Crossings

	Transit Street Crossing Distance							
Lanes	**1**	**2U**	**2D**	**3**	**4U**	**4D**	**5**	**6D**
ft	**15**	**24**	**28**	**36**	**48**	**54**	**60**	**78**
m	**4.6**	**7.3**	**8.5**	**11.0**	**14.6**	**16.5**	**18.3**	**23.8**
Assumed cycle length (s)	60	60	60	90	90	120	140	180
Assumed WALK time (s)	7	7	7	7	7	7	7	9
Delay (s)	20	20	20	35	35	50	59	78

SOURCE: Calculated from Equation 3-4, using default cycle length and WALK times shown. WALK time assumed to be the greater of 7 s or 5% of the cycle length.
NOTE: U=undivided, D=divided (with raised median or other pedestrian refuge)

Unsignalized Crossings. At unsignalized pedestrian crossings where pedestrians do not have the right-of-way (or where motorists do not grant pedestrians their legal right-of-way), average crossing delay is based on the crossing distance, average pedestrian walking speed, and traffic volumes (vehicle flow rates). Determining delay is a two-step process. First, the pedestrians' critical gap is determined, which is the shortest gap in traffic (in seconds) that pedestrians can safely use to cross the street. This can be determined from Equation 3-5:

Equation 3-5

$$t_{cg} = \frac{L_x}{S_p} + t_{ps}$$

where:

t_{cg} = pedestrian critical gap (s);
S_p = average pedestrian walking speed (ft/s, m/s);
L_x = crossing distance (ft, m); and
t_{ps} = pedestrian start-up and end clearance time (s).

Where elderly pedestrians make up 20% or less of the pedestrian population, a 4.0 ft/s (1.2 m/s) walking speed can be used; where elderly pedestrians are more numerous, a 3.3 ft/s (1.0 m/s) speed should be used. A default value of 3 seconds for pedestrian start-up and end clearance time may be used.[R16]

The 4.0-second default is not representative of all pedestrians. Field observations of pedestrian speeds may be appropriate in some circumstances.

Once the critical gap is known, Equation 3-6 can be used to determine pedestrian delay at unsignalized crossings where pedestrians do not have the right-of-way:[R16]

Equation 3-6

$$d_p = \frac{1}{v}\left(e^{vt_{cg}} - vt_{cg} - 1\right)$$

where:

d_p = average pedestrian delay (s);
v = vehicular flow rate (veh/s); and
t_{cg} = pedestrian critical gap (s).

In situations where a pedestrian refuge is provided in the middle of the street, and pedestrians tend to use that refuge to cross the street in two stages, delay should be determined individually for each direction of the street crossed, and then summed to determine the total delay. Exhibit 3-24 shows typical values of delay at unsignalized intersections, based on various combinations of lane widths, median types, and traffic volumes. As with signalized intersections, pedestrians start becoming impatient and exhibit risk-taking behavior when delay exceeds 30 seconds.(R16)

Where pedestrians have the right-of-way at an unsignalized crossing, they will experience a minimal amount of delay waiting to make sure that traffic will stop for them before they start to cross the street. This delay is well below the 30-second pedestrian impatience threshold used in Chapter 3 procedures.

Exhibit 3-24
Average Pedestrian Street Crossing Delay (s): Unsignalized Crossings with No Pedestrian Right-of-Way

Volume (veh/h)	Flow Rate (veh/s)	Crossing Distance 1 lane 15 ft 4.6 m	2 24 7.3	3 36 11.0	4 48 14.6	5 60 18.3	6 72 22.0
200	0.056	1	3	6	8	13	19
300	0.083	2	4	10	15	24	36
400	0.111	3	6	15	24	40	63
500	0.139	3	9	21	36	63	105
600	0.167	4	12	30	52	97	172
700	0.194	6	15	41	75	147	279
800	0.222	7	20	55	107	223	*
900	0.250	9	25	75	151	*	*
1,000	0.278	11	31	100	214	*	*
1,100	0.306	N/A	39	133	302	*	*
1,200	0.333	N/A	48	178	*	*	*
1,300	0.361	N/A	60	237	*	*	*
1,400	0.389	N/A	74	317	*	*	*
1,500	0.417	N/A	91	*	*	*	*
1,600	0.444	N/A	112	*	*	*	*
1,700	0.472	N/A	137	*	*	*	*
1,800	0.500	N/A	169	*	*	*	*
1,900	0.528	N/A	208	*	*	*	*
2,000	0.556	N/A	256	*	*	*	*

*Delay exceeds 5 minutes, 30 seconds (typical maximum pedestrian walking time to bus stops, plus 30 second pedestrian-impatience threshold).
N/A: not applicable—unlikely to achieve volumes shown with one lane.
SOURCE: Calculated from Equation 3-5 and Equation 3-6, using a pedestrian walking speed of 4.0 ft/s (1.2 m/s) and a pedestrian start-up and end clearance time of 3 seconds.

Other Measures

Researchers have developed more detailed ways of measuring service coverage that may be useful for some types of analyses. Further information about these measures can be found in *TCRP Report 88*(R17) and the references indicated below:

- *Percent people served* and *percent jobs served* are similar to the area-based service coverage measure presented above, but include all people or jobs served not just those living in higher-density areas.
- *Percent person-minutes served (TLOS Indicator)* was developed by the FDOT as a way of measuring service coverage, service frequency, and hours of service in combination. The FDOT provides GIS-based software and spreadsheets to help calculate this measure; the software is capable of evaluating actual walking paths to transit and not just air distances. Because the TCQSM's availability measures and the TLOS Indicator measure the same things, equivalent levels of service can be developed for TLOS Indicator values.(R18)
- The *Transit Service Accessibility Index* is similar to the TLOS Indicator, but looks at the number of trip ends exposed to transit service. The former is a measure of how well service demanded is served, while the latter is a measure of how much service is supplied. Either measure can be used to calculate an *adjusted mode split*—the number of trips made by transit where transit is available as a choice (i.e., in times and at places where transit service is offered), divided by the number of trips made by all modes.(R30)

- The *Local Index of Transit Availability* (LITA) measures the intensity of transit service in an area relative to the area's population and size. The LITA contains three components: frequency (transit vehicles per day), capacity (seat-miles divided by combined residential population and jobs), and route coverage (transit stops per square mile). The measure assesses relative differences in transit availability, rather than providing an absolute measure of the amount of transit availability.[R33]

Guidelines for Assessing Park-and-Ride Service Coverage

This section presents guidelines for including park-and-ride service coverage as part of a system's overall service coverage area. This procedure is not intended to serve as a tool for estimating potential park-and-ride demand; however, the park-and-ride references in Chapter 2 can be used for this purpose.

As was shown in Chapter 2, the area served by park-and-ride lots varies considerably by the type of lot, land uses within its market area, congestion on nearby roadways, and other factors specific to the metropolitan region where the lot is located. However, many of the studies are consistent in finding that approximately one-half of a park-and-ride lot's users start their trip within 2 to 3 miles (3 to 5 km) of the lot. This inner service area is a relatively compact area that can be used to assess a lot's service coverage. The outer service area will provide a similar number of users, but they will be scattered over an area four or more times as large as the inner service area, with the result that park-and-ride users within the lot's outer service area form a much smaller portion of the general population.

This procedure is similar to how bus stop coverage is treated. Approximately 25 to 30% of a bus stop's users will walk more than 0.25 mile (400 m) to a local bus stop, but these users will be spread over a large area and will form a much smaller portion of the general population in that area.

For the purposes of assessing service coverage, a 2.5-mile (4-km) radius around larger (100 spaces or more) park-and-ride lots may be used. This area should be added to the walking coverage area determined through either the planning or detailed methodologies described earlier. Because park-and-ride lots usually serve the home end of a trip, and often are designed to serve passengers who do not live in higher-density areas, *percent persons served* may be used as the park-and-ride lot performance measure, with the service area consisting of the transit agency's service area (e.g., a defined county or metropolitan area). When this measure is used, it should be reported in combination with walking service coverage performance.

Service coverage LOS for walking should still be reported when park-and-ride service coverage is measured.

The 2.5-mile (4-km) radius for urban area park-and-ride lots relates to larger facilities (typically 100 or more spaces), with enhanced transit service. For smaller lots (such as a 25-space shared church lot with only local transit service), a smaller service coverage area might be appropriate. Of course, if a more detailed park-and-ride market assessment related to a particular study or project is conducted, then the results of that study should supercede the method described above.

COMFORT AND CONVENIENCE—TRANSIT STOPS

From the passenger's perspective, passenger loads reflect the comfort level of the on-board vehicle portion of a transit trip—both in terms of being able to find a seat and in overall crowding levels within the vehicle. From a transit operator's perspective, a poor LOS may indicate the need to increase service frequency or vehicle size in order to reduce crowding and provide a more comfortable ride for passengers. A poor passenger load LOS indicates that dwell times will be longer for a given passenger boarding and alighting demand at a transit stop and, as a result, travel times and service reliability will be negatively affected.

Passenger load LOS is based on two measures: *load factor* (passengers per seat), when all passengers can sit, and *standing passenger area,* when some passengers must stand or when a vehicle is designed to accommodate more standees than seated passengers. Passenger load LOS can be measured by time of day (e.g., LOS "D" peak, LOS "B" off-peak) or by the amount of time a certain condition occurs (e.g., some passengers must stand for up to 10 minutes).

When a substantial number of passengers wear or carry objects such as daypacks or briefcases, that increase the space occupied by those passengers, analysts may wish to use the concept of *equivalent passengers,* based on the projected area values given in Exhibit 3-25. For example, a passenger wearing a daypack takes up about twice as much space as a passenger without one. If, on average, 5 of 10 standing passengers wear daypacks, then the space occupied by the standees is the equivalent of 15 unencumbered standing passengers.

Exhibit 3-25
Male Passenger Space Requirements[R4]

These are suggested minimum spaces.

Situation	Projected Area (ft^2)	Projected Area (m^2)
Standing	1.6-2.2	0.15-0.20
... with briefcase	2.7-3.2	0.25-0.30
... with daypack	3.2-3.8	0.30-0.35
... with suitcases	3.8-5.9	0.35-0.55
... with stroller	10.2-12.4	0.95-1.15
... with bicycle (horizontal)	17.2-20.4	1.60-1.90
Holding on to stanchion	2.7	0.25
Minimum seated space	2.7-3.2	0.25-0.30
Tight double seat	3.8 per person	0.35 per person
Comfortable seating	5.9 per person	0.55 per person
Wheelchair space (ADA)	10.0 (30 in x 48 in)	0.93 (0.76 m x 1.22 m)

NOTE: Stroller and bicycle dimensions are based on a review of manufacturer specifications.

The standing passenger area can be measured using a typical vehicle or estimated using the procedure described below. The area next to the vehicle operator, stepwells, interior steps, and wheel wells should not be included as part of the standing area. In addition, a 14-inch (0.36-m) buffer should be left in front of longitudinal seating to account for seated passenger foot room.

When the standing passenger area is not known, it can be estimated as follows:

1. *Calculate the gross interior floor area.* Multiply the vehicle width by the interior vehicle length. For standard buses, the interior vehicle length can be estimated by subtracting 8.5 feet (2.6 m) from the total bus length, as an allowance for the engine compartment and operator area.
2. *Calculate the area occupied by seats and other objects:*
   - Transverse seating: 5.4 ft^2 (0.5 m^2) per seat
   - Longitudinal seating: 4.3 ft^2 (0.4 m^2) per seat
   - Wheelchair position: 10.0 ft^2 (0.95 m^2) per position (use when the wheelchair position is not created by fold-up seats)
   - Rear door: 8.6 ft^2 (0.8 m^2) per door channel
   - Interior aisle stairs: 4.3 ft^2 (0.4 m^2)
   - Low-floor bus wheel well: 10.0 ft^2 (0.95 m^2) each
3. *Calculate the standing passenger area.* Subtract the area calculated in step 2 from the gross interior floor area calculated in step 1.

Exhibit 3-26 provides the LOS thresholds for passenger loads.

Exhibit 3-26
Fixed-Route Passenger Load LOS

LOS	Load Factor (p/seat)	Standing Passenger Area (ft²/p)	(m²/p)	Comments
A	0.00-0.50	>10.8†	>1.00†	No passenger need sit next to another
B	0.51-0.75	8.2-10.8†	0.76-1.00†	Passengers can choose where to sit
C	0.76-1.00	5.5-8.1†	0.51-0.75†	All passengers can sit
D	*1.01-1.25**	3.9-5.4	0.36-0.50	Comfortable standee load for design
E	*1.26-1.50**	2.2-3.8	0.20-0.35	Maximum schedule load
F	*>1.50**	<2.2	<0.20	Crush load

*Approximate value for comparison, for vehicles designed to have most passengers seated. LOS is based on area.
†Used for vehicles designed to have most passengers standing.

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

Other Measures

Other measures of passenger comfort at transit stops are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the TCQSM sections identified with particular measures in the following list:

- *Reliability* is discussed in the next section under route segments and corridors, as it tends not to vary between adjacent stops. However, for a passenger waiting at a particular stop, that passenger's perception is that the transit vehicle is late arriving at his or her stop.
- The kinds of *amenities* provided at transit stops are usually a matter of agency policy, based on the number of boarding riders that would benefit from an amenity, along with other factors. Part 7 lists common transit amenities, typical ranges of boarding passengers used by transit systems to warrant their installation, and other factors which should be considered.
- Other aspects of passenger *comfort* are best measured through customer satisfaction surveys and passenger environment surveys.
- *Security* is important to passengers, but can be difficult to quantify at the stop level, as it is often difficult to distinguish between crimes that happen to occur near a transit stop or station and those that occur to persons in the process of making a transit trip.

Customer satisfaction and passenger environment surveys are discussed in Chapter 2.

COMFORT AND CONVENIENCE—ROUTE SEGMENTS/CORRIDORS

Several different measures of reliability are used by transit operators. The most common of these are

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

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

On-Time Performance

TCRP Synthesis of Transit Practice 10[R5] reviewed more than 80 agencies' on-time performance standards, as they existed in 1994. A summary of these standards is presented in Exhibit 3-27. Of the surveyed agencies, 42% allowed buses to be more than 5 minutes late and still be considered "on-time," and 24% allowed some early buses to be considered on-time.

Exhibit 3-27
On-Time Performance Standards of Surveyed U.S. Transit Agencies[R5]

	Number of Surveyed Agencies Using Standard	
On-Time % Standard	**Peak**	**Off-Peak**
98-100%	12	14
94-97%	17	29
90-93%	24	20
85-89%	8	7
80-84%	9	4
75-79%	7	4
70-74%	4	3
<70%	2	2

Canadian transit operator on-time performance standards are less lenient than those of their U.S. counterparts. Of the 17 agencies surveyed by the Canadian Urban Transit Association that define an on-time performance standard, 11 use 95% on-time as their standard, with "on-time" defined as being no more than 3 or 4 minutes late. The other six agencies have standards between 80% and 95%, with "on-time" defined as being up to 5 minutes late. Only two of the seventeen agencies allowed early buses.[R7]

Early departures.

From the perspective of a passenger arriving close to the time a transit vehicle is scheduled to depart, an early departure is not on-time; rather, it is equivalent to a vehicle being late by the amount of one headway in terms of when the passenger can board a vehicle. On the other hand, an early arrival towards the end of the route, where no passengers are boarding, would not be seen as a problem by passengers on the bus and would likely be viewed positively.

A review of the on-time performance achieved by three larger transit agencies, conducted as part of the development of the TCQSM Second Edition, found that early running was a significant contributor to non-"on-time" performance (and thus low on-time performance LOS). Data were obtained from automatic vehicle location (AVL) equipment that recorded departure times from timepoints and compared these departure times to the scheduled time. In some cases, more than 50% of the buses that would be considered not on-time (with "on-time" defined as a departure from a timepoint 0 to 5 minutes late) were running early. For two of the three systems, the average early bus was 3 to 4 minutes ahead of schedule.

Exhibit 3-28 shows on-time performance results from these three agencies at the next-to-last timepoint along routes, during the weekday p.m. peak period. Data for agencies #1 and #2 represent a sampling of trips over 1 month; data for agency #3 represents data from all p.m. peak hour trips over 1 week. As can be seen, early running was a major contributor to low on-time performance, even during a time of day when traffic congestion, passenger volumes, and other factors would be expected to cause on-time performance problems.

Exhibit 3-28
Sample On-Time Performances—Weekday P.M. Peak at the Next-to-Last Timepoint

		Systemwide On-Time Performance	
Agency	**Trips Observed**	**Unadjusted**	**Adjusted for Early Departures**
#1—June/July 2001	173	77%	88%
#2—July/August 2001	1,290	74%	86%
#2—October 2001	179	69%	76%
#3—October 2001	5,300	61%	84%

On-time performance should be measured at locations of interest to passengers. For example, measuring on-time performance at the next-to-last timepoint may be of more interest than measuring it at the route terminal, if most passengers disembark prior to the end of the route. On the other hand, if the route terminal is a timed-transfer center, on-time performance arriving at that location would be of great interest to passengers. Some agencies measure on-time performance at several timepoints along a route.

Measure on-time performance at locations of interest to passengers.

On-time performance LOS defines "on-time" as being 0 to 5 minutes late. Whether arrivals or departures should be measured will depend on the situation: departures tend to be more important where passengers are mostly boarding, and arrivals where passengers are mostly disembarking. Early departures should not be considered on-time in locations where passengers are boarding, but early arrivals may be considered on-time at the end of a route or at other locations where passengers are only disembarking. On-time performance measurement can be applied to any transit service operating with a published timetable, but is particularly applicable to services operating with headways longer than 10 minutes. At shorter headways, the evenness of headways between vehicles becomes more important to measure, as vehicle bunching leads to a variety of operating and quality of service problems. Headway adherence LOS is discussed below.

Early departures are not considered on-time at stops where passengers board.

LOS ranges for on-time performance are presented in Exhibit 3-29. On-time performance would typically be measured for a route over a series of days (either over consecutive days or as a monthly sampling of each trip) or as a system-wide value. Note that it takes a minimum of 20 observations to achieve the 5% resolution between LOS grades (more observations may be needed to achieve a particular level of statistical significance). The comments shown for each LOS grade reflect the perspective of a passenger who makes one round-trip by transit each weekday (e.g., 10 boardings per week to and from work, if no transfer is required).

Exhibit 3-29
Fixed-Route On-Time Performance LOS

LOS	On-Time Percentage	Comments*
A	95.0-100.0%	1 late transit vehicle every 2 weeks (no transfer)
B	90.0-94.9%	1 late transit vehicle every week (no transfer)
C	85.0-89.9%	3 late transit vehicles every 2 weeks (no transfer)
D	80.0-84.9%	2 late transit vehicles every week (no transfer)
E	75.0-79.9%	1 late transit vehicle every day (with a transfer)
F	<75.0%	1 late transit vehicle at least daily (with a transfer)

NOTE: Applies to routes with a published timetable, particularly to those with headways longer than 10 minutes.
"On-time" is 0 to 5 minutes late, and can be applied to either arrivals or departures, as appropriate for the situation being measured. Early departures are considered on-time only in locations where no passengers would typically board (e.g., toward the end of a route).
*Individual's perspective, based on 5 round trips per week.

At LOS "A," passengers experience highly reliable service and are assured of arriving at their destination at the scheduled time except under highly unusual circumstances. Service is still very reliable at LOS "B," but an average passenger will experience one late transit vehicle per week. At LOS "C," an average passenger will experience more than one late vehicle per week on average. At LOS "D" and "E," passengers become less and less assured of arriving at the scheduled time, and may choose to take an earlier trip to ensure getting to their destination by their desired time. At LOS "F," the number of late trips is very noticeable to passengers.

Headway Adherence

For transit service operating at headways of 10 minutes or less, headway adherence is used to determine reliability. The measure is based on the coefficient of variation of headways of transit vehicles serving a particular route arriving at a stop, and is calculated as follows:

Equation 3-7

$$c_{vh} = \frac{\text{standard deviation of headway deviations}}{\text{mean scheduled headway}}$$

where:
c_{vh} = coefficient of variation of headways.

Headway deviations are measured as the actual headway minus the scheduled headway. As shown in Exhibit 3-30, the coefficient of variation of headways can be related to the probability P that a given transit vehicle's headway h_i will be off-headway by more than one-half the scheduled headway h. This probability is measured by the area to the right of Z on one tail of a normal distribution curve, where Z in this case is 0.5 divided by c_{vh}. For an illustration of these relationships, see page 4-8.

Exhibit 3-30
Fixed-Route Headway Adherence LOS

LOS	c_{vh}	$P(h_i > 0.5\ h)$	Comments
A	0.00-0.21	≤1%	Service provided like clockwork
B	0.22-0.30	≤10%	Vehicles slightly off headway
C	0.31-0.39	≤20%	Vehicles often off headway
D	0.40-0.52	≤33%	Irregular headways, with some bunching
E	0.53-0.74	≤50%	Frequent bunching
F	≥0.75	>50%	Most vehicles bunched

NOTE: Applies to routes with headways of 10 minutes or less.

At LOS "A," service is provided like clockwork, with very regular headways. At LOS "B," most vehicles are off the scheduled headway by a few minutes, but the probability of being off-headway by more than one-half the scheduled headway is low. At LOS "C," vehicles are often off-headway, with a few headways much longer or shorter than scheduled. Headways between vehicles at LOS "D" levels are quite irregular, with up to one in three vehicles one-half a headway or more off-headway. Bunching occurs frequently at LOS "E," and most vehicles are bunched at LOS "F." The following examples illustrate some of these LOS ranges.

Example Calculations

Example 1. A bus route is scheduled to operate at fixed 10-minute headways. During the peak hour, the actual measured headways between buses are 12, 8, 14, 6, 7, and 13 minutes. The corresponding headway deviations are +2, -2, +4, -4, +3, and -3 minutes. The standard deviation of these values is 3.4 minutes, and the resulting coefficient of variation is 0.34, equivalent to LOS "C."

Example 2. Another bus route is scheduled at 5- to 11-minute headways during the peak period. The following table provides the scheduled headway between buses, the actual headway (based on AVL data), and the corresponding headway deviation.

Scheduled Headway (s)	600	600	600	600	660	600	420	540	540	420	420	420	360	300
Actual Headway (s)	786	906	700	302	616	198	304	918	538	120	308	876	168	134
Headway Deviation (s)	+186	+306	+100	-298	-44	-402	-86	+378	-2	-300	-112	+456	-192	-166

The mean headway is 506 seconds, the standard deviation of the headway deviations is 265 seconds, and the coefficient of variation is 0.52, equivalent to LOS "D."

Other Measures

Other measures of passenger convenience along route segments and corridors are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the references given in the following list:

- *Travel speed* is a useful route segment performance measure, because it reflects how long a trip may take, without depending on the length of a route segment. Transit priority measures, improvements to fare collection procedures, and other similar actions implemented along a route segment will be reflected as improvements in travel speed. The procedures in Parts 4 and 5 can be used to estimate transit travel speeds along a route segment. *TCRP Report 26*[(R34)] provides suggested LOS ranges based on bus speeds for buses operating on arterial bus lanes.
- MTA-New York City Transit uses *wait assessment* as its measure of headway regularity. The measure is defined as the percentage of transit vehicle arrivals where the actual headway exceeded the scheduled headway by more than 3 minutes. (Headways less than those scheduled are not considered, under the theory that short headways generally result from the previous vehicle's long headway and the vehicle with the long headway is the one that affects passenger service quality, as a result of longer wait times and more crowded conditions on board.)

COMFORT AND CONVENIENCE—SYSTEM

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

The level of service measure is *transit-auto travel time*: the door-to-door difference between automobile and transit travel times, including walking, waiting, and transfer times (if applicable) for both modes. It is a measure of how much longer (or in some cases, shorter) a trip will take by transit. The trip length is not as important as the trip time—a 20-mile trip that takes 1 hour longer by transit and a 5-mile trip that takes 1 hour longer both require an extra hour out of one's day—although longer trips have a greater potential for having a greater time differential.

Travel time for transit includes walk time from one's origin to transit (assumed to be an average of 3 minutes), wait time (5 minutes), travel time on-board transit (varies), walk time from transit to one's destination (3 minutes), and any transfer time required (varies). Travel time for automobiles includes travel time in the automobile and time required to park one's car and walk to one's destination (assumed to be an average of 3 minutes). Walk time is based on a maximum 0.25-mile (400-m) walk to transit at 3 mph (5 km/h), which will take about 5 minutes; not all transit users walk the maximum distance.

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

Since transit-auto travel time is a system measure, its data requirements are greater than those for transit stop and route segment measures. This section presents two methods for calculating transit-auto travel time LOS: one uses a transportation planning model and the other is done by hand.

As with many of the other service measures, transit-auto travel time can be measured at different times of the day, for example, at peak and off-peak times. Because peak hour traffic congestion tends to lengthen automobile trip times, the calculated LOS will often be better during peak hours than during the rest of the day. Exhibit 3-31 provides the transit-auto travel time LOS thresholds:

Exhibit 3-31
Fixed-Route Transit-Auto Travel Time LOS

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

Door-to-door travel by transit is faster than by auto at LOS "A." This level of service provides considerable incentive to potential riders to use transit. At LOS "B," the in-vehicle travel times by auto and transit are comparable, but the walk and wait time for transit makes the total trip by transit slightly longer. Riders must spend an extra hour per day using transit at LOS "C" levels and up to 1.5 hours at LOS "D." At LOS "E," individual trips take up to 1 hour longer by transit than by automobile; however, this may be the best possible in small cities where automobile travel times are low. Travel times at LOS "F" levels will be unacceptable to most riders.

Example Calculations

Transportation Planning Model Method

The advantage of using a transportation planning model is that all trips between all zones can be modeled and different kinds of trip types can be compared. Since many urban areas only have a weekday p.m. peak hour model, travel times at other times of the day and week cannot be compared using this method. The transportation model used needs to include networks for both roadways and transit.

Step 1: Calculate travel time differences between zones. Use the transportation planning model to generate (1) a table of automobile travel times between each pair of zones and (2) a table of transit travel times between each pair of zones. Subtract the values in the transit table from the values in the automobile table to obtain travel time differences between each pair of zones.

Step 2: Calculate total person trips between zones. From the model, generate a table of total person trips (both automobile and transit) between each pair of zones.

LOS can be measured as a system average or for individual origin-destination pairs.

Step 3: Calculate the weighted average of travel time differences. For each pair of zones, multiply the travel time difference between the zones by the number of person trips between the zones. Sum all of the resulting values and divide by the total number of person trips that took place. The result is a system-wide weighted average travel time difference, which can then be used with Exhibit 3-31 to calculate a system-wide LOS. The LOS for individual origin-destination pairs can also be calculated.

Manual Method

The manual method is useful in areas without a transportation model or when a faster assessment of travel time LOS is desired. A sampling of about 10 to 15 locations should be used for the analysis. In general, the CBD and 10 to 15 important trip generators should be used, with a balance of residential and employment generators and a balance of geographic locations. Unless there is a heavy reverse-direction volume during the analysis period or the reverse volume is of interest to the analysis (for example, for welfare-to-work applications), estimating peak direction travel times is usually sufficient.

Step 1: Estimate travel times between locations. Analysts may find it useful to sketch two simple network diagrams of the area being studied, one for transit and one for automobiles, and to indicate travel times on the links between locations. Analysts may also find it useful to create a spreadsheet of travel times between locations for use in subsequent steps. During step 1, only travel times between locations and transfer times are considered; access and wait times are not considered. For an analysis of existing conditions, transit travel and transfer times can be derived from published schedules; automobile travel times can be determined by driving the main routes between locations. When a choice of transit routes is available, the fastest route (e.g., an express route) should be selected.

Step 2: Estimate travel time differences between locations. For each pair of locations, subtract the auto travel time from the transit travel time; add transit access, wait, and transfer times; and subtract any auto access time (e.g., walks to or from parking garages).

Step 3: Calculate the level of service. Average the travel time differences of each pair of locations and use the resulting system value with Exhibit 3-31, or calculate point-to-point LOS directly from Exhibit 3-31.

An example of the manual calculation method can be found in the example problems in Chapter 6.

Other Measures

Other measures of passenger convenience along route segments and corridors are listed below. Further information about these measures can be found in *TCRP Report 88*(R17) and in the references identified with particular measures in the following list:

- *Transit/auto travel time ratio* is sometimes used by transit agencies as a service design standard (e.g., a trip by transit should not take longer than twice the time it would take by automobile). This measure can produce large values in smaller cities, where auto travel times are often short relative to transit.
- Rather than compare transit and automobile travel times, the transit *travel time* can be used by itself as a performance measure. The maximum time that passengers will find reasonable will vary, depending on the size of the city or metropolitan area served by transit, and whether travel is occurring during peak or off-peak times.(R10)
- *Safety* measures reflect the probability of being injured while using transit, for example, due to a vehicle crash or a slip and fall. *Security* measures reflect the probability of being a victim of a crime while using transit.

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CHAPTER 4. DEMAND-RESPONSIVE TRANSIT SERVICE MEASURES

INTRODUCTION

This section describes a quality of service evaluation framework for demand-responsive transportation (DRT). It can also be used for evaluating specialized transportation services, including ADA paratransit. However, it must be recognized that specialized services are, by definition, provided to specific user groups and are not available to the general public. ADA paratransit service, in particular, is heavily regulated, and transit systems must ensure compliance with the federal regulations or face potential legal ramifications. However, for an assessment of service quality from the same perspective of the DRT evaluation framework, the methodology described in this section could be used for ADA paratransit.

Consistent with the evaluation framework for fixed-route transit, the service measures for DRT are provided within two categories: (1) availability and (2) comfort and convenience. Within the two categories, some of the DRT measures parallel those for evaluating fixed-route services. Given the fundamental differences between the two modes, however, the TCQSM presents this separate framework for DRT. Instead of defining LOS on an "A" to "F" scale as with fixed-route transit, a "1" to "8" scale has been established for DRT. This reflects a desired further gradation of LOS thresholds for DRT than could be described on an "A" to "F" scale.

Demand-responsive transit LOS uses a numerical "1" to "8" scale.

There is no DRT equivalent for the "transit supportive area" used in the fixed-route transit framework. Readers interested in estimating demand for rural DRT service are referred to *TCRP Report 3.*[R35]

AVAILABILITY—RESPONSE TIME

Response time is the minimum amount of time a user needs for scheduling and accessing a trip or the minimum advance reservation time. This measure is most appropriate where most of the trips are scheduled each time that the user wants to travel. In other words, it is less appropriate where most of the trips are provided on a standing-order, subscription basis, where riders are picked up on pre-scheduled days at pre-scheduled times and do not need to call in advance for each trip. Nevertheless, the measure could be used where subscription service is provided. For such DRT services, response time could be calculated for the situation when a trip request is first made. Exhibit 3-32 shows the response time associated with each LOS.

Exhibit 3-32
DRT Response Time LOS

LOS	Response Time	Comments
1	Up to ½ hour	Very prompt response; similar to exclusive-ride taxi service
2	More than ½ hour, and up to 2 hours	Prompt response; considered immediate response for DRT service
3	More than 2 hours, but still same day service	Requires planning, but one can still travel the day the trip is requested
4	24 hours in advance; next day service	Requires some advance planning
5	48 hours in advance	Requires more advance planning than next-day service
6	More than 48 hours in advance, and up to 1 week	Requires advance planning
7	More than 1 week in advance, and up to 2 weeks	Requires considerable advance planning, but may still work for important trips needed soon
8	More than 2 weeks, or not able to accommodate trip	Requires significant advance planning, or service is not available at all

DRT service that is provided at LOS "1" is similar to exclusive-ride taxi service, with very prompt response. Such response time is possible where scheduling/ dispatch is provided on a real-time basis, where service is operated by a taxi company, and where there is limited or no shared-riding. DRT service at LOS "2" would have the capacity to provide trips within 2 hours of a user's request for a trip. While not as prompt as LOS "1," it is considered immediate response service for DRT and allows relatively spontaneous trips to be made. At LOS "3," service response is longer than 2 hours but service is still available the same day that a trip is requested. For general public users, this is lesser quality service, but still enables one to travel on the day requested though perhaps not at the exact time desired. With LOS "4" service, trip requests are made the day before service is needed. For many DRT users, this may be satisfactory service as many trips tend to be somewhat pre-planned. Beyond LOS "4," additional advance planning is necessary, until LOS "8," where a trip must be planned more than 2 weeks into the future or, very undesirably from the user's perspective, service is not available at all.

Response time LOS should be based on actual operating experience, rather than stated policy.

Assessment of response time should be based on actual operating experience. It should not be based solely on the stated policy of the DRT system.

To calculate this measure, the DRT provider should look at the minimum amount of time that a user needs to schedule a trip in relation to the response time policy. For example, if the stated policy of the DRT system is that service is provided 24 hours in advance, then the provider should determine if users can systematically schedule a trip the day before the trip is desired. Some portion of users will schedule trips more than 24 hours in advance, but if the policy is 24 hours in advance, then a user should be able to reserve a trip the day before the desired trip.

Information on response time can be obtained from DRT staff that book trips, typically telephone reservationists/schedulers or dispatchers. Another approach is to survey riders to obtain their input and experience with response time.

Using an average for this measure is not appropriate, as some DRT users call far in advance to schedule a trip, even though this may not be necessary. For example, a particular user may call 1 week in advance to schedule an important trip on a DRT system that has 24-hour response time, even though the user could call the day before to get the ride. An average would capture such response times for trips scheduled farther in advance than is necessary and would thus not be representative of actual operations.

AVAILABILITY—SERVICE SPAN

Service span measures the number of hours during the day and days per week that DRT service is available in a particular area. Unlike the similar measure for fixed-route service that measures hours per day of service, the service span measure for DRT incorporates *days* of service in addition to *hours* per day. This is done because in some rural areas DRT service may only be provided selected days per week, or even selected days per month. Incorporation of both hours per day and days per week provides a more complete perspective on the amount of DRT service that is available within a community or larger area. Given that the measure incorporates two factors, it is presented as a matrix.

To use the matrix, first determine how many days per week the DRT service operates. From the column in Exhibit 3-33 that shows the number of days per week, determine the hours per day that service is provided. For DRT systems that operate different hours during the week than during the weekend, a weighted average can be calculated. For example, a DRT system that operates 6 a.m. to 7 p.m. on weekdays and 7 a.m. to 5 p.m. on Saturdays, provides service 6 days per week, for a weighted average of 12.5 hours. This would be LOS "2."

	Days Per Week						
Hours Per Day	**6-7**	**5**	**3 - 4**	**2**	**1**	**0.5***	**< 0.5**
≥16.0	LOS 1	LOS 2	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
12.0-15.9	LOS 2	LOS 3	LOS 4	LOS 5	LOS 6	LOS 7	LOS 8
9.0-11.9	LOS 3	LOS 4	LOS 4	LOS 6	LOS 6	LOS 7	LOS 8
4.0-8.9	LOS 5	LOS 5	LOS 5	LOS 6	LOS 7	LOS 7	LOS 8
< 4.0	LOS 6	LOS 6	LOS 6	LOS 7	LOS 8	LOS 8	LOS 8

*service at least twice per month

Exhibit 3-33
DRT Service Span LOS

For DRT service availability, there are several key thresholds related to the service span. The first is whether there is any weekend service. In many communities with DRT, service is provided just during the week. This is considered satisfactory service and perfectly acceptable for a majority of users, but does limit trip-making to weekdays only, with no service on Saturdays or Sundays.

A second related threshold considers whether service is available all weekdays. Monday through Friday service is considered standard and is important for users, allowing them to travel throughout the week. DRT service that is available only several weekdays each week cannot be considered particularly high quality from an availability perspective, even though it may be the only financially feasible service in some communities.

A third threshold relates to length of the service day. In smaller communities and rural areas, DRT service is often provided just during the business day, for example, 9 a.m. to 5 p.m. While such a service span allows users to travel by DRT for medical appointments, shopping trips, and other similar trips, a person working a full-time office job could not use the DRT system to travel back and forth to work. Such DRT systems with service hours of less than 9 hours per day are most appropriate as specialized transit programs focused on targeted clienteles.

A fourth threshold relates to whether service is available at least weekly. While service in urban areas and most small communities is provided at least on weekdays or several days per week, some rural areas receive service on less than a weekly basis. This is sometimes referred to as *lifeline* service, allowing the rural residents access to shopping areas and other destinations at least once or several times per month. And while such service may be appreciated by users who are transit dependent, it is very limited quality from the user's perspective in relation to its availability.

The LOS levels shown in Exhibit 3-33 reflect the thresholds identified above, with marked LOS gradations between the thresholds. For example, at LOS "1," DRT service is highly available, with service available 6 or 7 days per week and from early morning hours to very late at night. Such service availability might be typical of an urban ADA paratransit program that provides service during hours comparable to the city's fixed-route transit system. At LOS "2," service is available weekdays and during daytime and at least early evening hours as well. However, service that is available only 4 days per week, even with a long service day, is LOS "4." Service availability less than once per week is LOS "7" or "8." While this amount of service may be the best that can be provided in a rural area given low population densities and limited funding, it is not desirable from the user's perspective.

This measure can also be used to assess any differences in service availability across a transit agency's service area. For example, a transit agency serving a large county that includes several small communities may establish different service spans within different parts of the county. The communities in the county may receive DRT service on a more frequent basis than the outlying rural parts of the county. In such a case, the communities in the county would have a higher LOS on the service span measure than would the rural parts of the county. From the user's perspective, DRT service in the communities is higher quality than that in the rural areas, as the service span is greater.

COMFORT AND CONVENIENCE—RELIABILITY

Reliability of DRT is a critical issue from the user's perspective. Users will want to know: "Will there be a trip for me when I call, or will all the rides be taken?" "Once I book my ride, will the vehicle arrive at the scheduled time?" "Will the driver get me to my destination before my appointment time, or will my trip be too long?"

Because of the nature of DRT, where a user must schedule individual trips, there is more variability in DRT operations than there is for fixed-route service. For fixed-route bus service, a rider simply walks out to a marked bus stop along the published route a few minutes before the published or estimated time that the vehicle will pass by. The rider boards the bus and gets off at the appropriate stop at the published or estimated time.

For DRT service, there are several steps involved in taking a trip, each with reliability issues. The user must call or contact the DRT office to request the particular trip. Depending on available capacity of the DRT system, the user may or may not be able to reserve a trip. If there is capacity, the trip may or may not be available at the exact time the user requests. Once the trip is booked, the user must wait for the vehicle and driver to arrive at the scheduled time (often this is a window of time rather than an exact time). The vehicle and driver may arrive on time (within the window) or late, or there may be times when the vehicle does not arrive at all. Once aboard the vehicle, the user then rides until arrival at the scheduled destination, which will take a varying amount of time depending upon other riders who might be sharing the vehicle and their trip characteristics. If everything goes as scheduled, the user arrives at his or her destination on time.

Given the various steps involved within a DRT trip, reliability is assessed with two measures: *on-time performance* and *trips not served*.

On-Time Performance

On-time performance measures the degree to which DRT vehicles arrive at the scheduled times. The measure is calculated at the pick-up location and, for time-sensitive trips (e.g., medical appointments, work, school, etc.), at the drop-off location as well.

Many DRT systems, particularly those in urban areas, give users a "window of time" that the vehicle will arrive. For example, if a user requests a 10 a.m. pick-up, the scheduler or dispatcher might tell that user that the vehicle can be expected between 9:45 and 10:15 a.m. If the vehicle arrives any time within that 30-minute window, it is considered on time. With the routing variability and shared-ride nature of DRT service, it is difficult to give users an exact time that the vehicle will arrive.

On-time performance is usually measured to ensure that vehicles do not arrive late. However, being *early* can be a problem, too, in that users may feel compelled to hurry outside to meet their vehicle at the pick-up end, and, at the destination end, an early arrival may mean the user gets to an appointment before the building or establishment is even open. Early arrivals may also result in no-shows. When drivers arrive early, they may not find their passengers waiting at the pick-up location because it's too early and then, prematurely, may mark those passengers as no-shows and proceed. Generally, DRT systems require that drivers who arrive early for the pick-up wait at the location until the on-time window begins before starting the "official" waiting time for the passenger, typically up to 5 minutes or sometimes longer depending on the type of DRT system.

Calculating on-time performance is done on a percentage basis for all trips during the defined time period or for a sample of trips over the time period. All trips should be assessed at the pick-up end to determine whether they are within the on-time window. Time-sensitive trips would be assessed at the destination end to see if the vehicle arrived at or before the required time.

The window of time can be determined by the local system. Particularly in larger DRT systems, the on-time window is 30 minutes; however, some DRT systems use a shorter 20-minute or 15-minute window for scheduling trips and assessing timeliness. In some rural areas, DRT systems may have a much longer window—60 minutes, for example. Shorter windows provide a higher service quality to users, as the users' waiting period for service is shorter. Those DRT systems that use a longer window should provide a higher percentage of trips on time, given the longer time frame allowed for arriving at the scheduled locations. Thus, the LOS thresholds given in Exhibit 3-34 may need adjustment depending upon the definition of on-time.

Exhibit 3-34
DRT On-Time Performance LOS

LOS	On-Time Percentage	Comments*
1	97.5-100.0%	1 late trip/month
2	95.0-97.4%	2 late trips/month
3	90.0-94.9%	3-4 late trips/month
4	85.0-89.9%	5-6 late trips/month
5	80.0-84.9%	7-8 late trips/month
6	75.0-79.9%	9-10 late trips/month
7	70.0-74.9%	11-12 late trips/month
8	<70.0%	More than 12 late trips/month

NOTE: Based on 30-minute on-time window.
*Assumes user travels by DRT round trip each weekday for one month, with 20 weekdays/month.

Given the variability of DRT service operations on a day-to-day basis including the unpredictability of dwell times for individual DRT riders, the shared-ride nature of the service, and the vagaries of traffic, particularly in urban areas, achievement of LOS "1" is very high quality service and certainly difficult to achieve in an urban area. In smaller communities, LOS "1" would be more achievable. For a user riding DRT round-trip each weekday for 1 month, LOS "1" would mean no more than one late trip experienced by that user during the month. At LOS "2," 95% of trips are on-time, still high-quality service. At LOS "3," 90% of trips are on-time. While this measure does not assess how late the late trips are, assuming that they are not more than 15 to 30 minutes late, then the DRT service may still be relatively good from the user's perspective. At LOS "4," more trips are outside the on-time window, resulting in less timeliness and reliability for users. For the remaining LOS thresholds, the percentage of trips arriving within the window decreases, until LOS "8," where less than 70% of trips are on-time. For a regular user, riding the DRT system on a daily basis to school, for example, this would mean that in a given month more than 12 trips would be late. This would be very undesirable from that user's perspective.

Trips Not Served: Trips Denied and Missed Trips

Trips not served is a measure that includes two components: (1) trips turned down or denied when requested because of a lack of capacity and (2) missed trips, which are those booked and scheduled but the vehicle does not show up. From a user's perspective, a DRT system is reliable if that user can book a trip when needed and the vehicle shows up when scheduled—in other words, no (or very minimal) trips not served. Conversely, the DRT service is unreliable if the user cannot obtain a trip—either because the trip is denied or because the vehicle never shows up for the scheduled trip. Some DRT providers try to avoid denials by over-accepting trips, which then results in missed trips, as there is inadequate capacity. Other DRT providers may have a higher number of denials in order to guarantee capacity to serve those trips that they do accept, with a resulting minimal number of missed trips. This composite measure of trips not served captures both circumstances—denials and missed trips—which result in the same consequence for the user: a trip not served.

From a DRT provider's perspective, trips not served must be assessed separately from denials. Frequent trip denials indicate that the DRT system does not have enough capacity. Frequent missed trips can stem from a number of causes, including trip scheduling that is too tight, with inadequate time for drivers to carry out their manifest; inexperienced drivers who cannot find pick-up locations; miscommunications between users and schedulers/dispatchers as to where to meet the driver and vehicle, particularly at activity centers or locations with multiple entrances; inadequate number of vehicles due to breakdowns, defects, or other reasons; insufficient number of drivers; or a combination of these factors. Exhibit 3-35 provides the LOS thresholds for trips not served.

Exhibit 3-35
DRT Trips Not Served LOS

LOS	Percent Trips Not Served	Comments*
1	0-1%	No trip denials or missed trips within month
2	>1%-2%	1 denial or missed trip within month
3	>2%-4%	1-2 denials or missed trips within month
4	>4%-6%	2 denials or missed trips within month
5	>6%-8%	3 denials or missed trips within month
6	>8%-10%	4 denials or missed trips within month
7	>10%-12%	5 denials or missed trips within month
8	>12%	More than 5 denials or missed trips within month

NOTE: Trips not served include trip requests denied due to insufficient capacity, and missed trips.
*Assumes user travels by DRT round trip each weekday for one month, with 20 weekdays/month.

At LOS "1," DRT service is very reliable, with no or very isolated denials or missed trips. This is high-quality service, where the DRT system is able to successfully provide capacity for the varying levels of demand throughout the day and ensure effective on–street operations with no or a minimal number of missed trips. LOS "2" service is still quite reliable. From the perspective of a user who travels by DRT each weekday without a standing order ride[1], LOS "2" might entail one denial or missed trip on a monthly basis, depending on the number of weekdays in the month. The percentage of denials/missed trips increases with each LOS threshold. At LOS "8," the user who travels by DRT each weekday would experience more than five denials or missed trips in the month; this is clearly unreliable service from that user's perspective.

COMFORT AND CONVENIENCE—TRAVEL TIME

Travel time is an important measure for DRT users. Some users may compare their DRT travel time to that for a comparable auto trip. Others may compare their DRT trip with a comparable trip on fixed-route service. Still other users may compare DRT travel time with some pre-set length of time, for example, 30 minutes, or perhaps the "usual" travel time for their DRT trips.

A user should expect that travel times on DRT will be somewhat longer than on a private vehicle, due to the shared ride nature of the service, with deviations during the trip for other riders. However, the user also expects that the deviations should not result in a trip that is too lengthy. Defining "too lengthy" will depend on the characteristics of the service area and the type of trip being taken. For example, a DRT trip in a rural area or a regional trip in an urban area might legitimately be 60 to 90 minutes long because of its long length in miles and, in the urban area, because of traffic congestion. However, for a short trip within the community, 60 minutes is excessively long, even with shared riding.

While individual transit systems may set actual numerical values for travel time to assess the quality and performance of their DRT trip travel times (based on their average trip lengths, types of trips, and known service area characteristics), a more

[1] Users with standing order rides do not need to call the DRT office for each ride, thus they do not face denials for these rides. However, any type of trip may be a missed trip.

generic measure will compare DRT travel times with other travel choices. This manual's quality of service framework compares DRT travel time with automobile travel time, in a similar way to that for fixed-route transit in Chapter 3.

DRT-Auto Travel Time

This measure assesses the door-to-door difference between DRT and automobile travel times and is parallel to the travel time measure for fixed-route service. Travel time for DRT includes the in-vehicle time for the trip; it does not include the waiting time for the vehicle to arrive (in this regard, the measure is different from its fixed-route counterpart). Travel time for autos includes the travel time in the vehicle, time to park the vehicle, and time to walk to one's destination, which is the same calculation as that used for the fixed-route transit measure. LOS thresholds for this measure are given in Exhibit 3-36.

Exhibit 3-36
DRT-Auto Travel Time LOS

LOS	Travel Time Difference (min)	Comments
1	≤0	The same or slightly faster by DRT as by automobile
2	1-10	Just about the same or slightly longer by DRT
3	11-20	Somewhat longer by DRT
4	21-30	Satisfactory service
5	31-40	Up to 40 minutes longer by DRT than by automobile
6	41-50	May be tolerable for users who are transit-dependent
7	51-60	May indicate a lot of shared riding or long dwell times
8	>60	From most users' perspectives, this is "too lengthy"

At the highest LOS, average DRT trips are comparable to those by private automobile. This is very high quality service from a user's perspective, as it indicates no shared riding. At LOS "2," DRT trips are just about the same or slightly longer than the same trip by private car. At LOS "3," DRT trips are somewhat longer, and at the LOS "4," DRT trips are up to 30 minutes longer than by automobile. Such trips, however, may still be considered satisfactory as the users are picked up at their residences and dropped off directly at their destinations. Travel time differences continue to increase with each LOS threshold, until LOS "8," where DRT service is more than 1 hour longer than the comparable trip by automobile. For most users, this would be undesirable.

A high LOS may be undesirable from a DRT provider's perspective.

It should be noted that these LOS thresholds at the higher quality levels are quite different from the DRT provider's perspective. A DRT provider wants shared riding to improve efficiency and productivity. If trips consistently have the same or similar travel time as trips by auto, it indicates that the scheduling/dispatch function is failing to group rides. One of the skills for scheduling/dispatching is balancing the degree of shared riding with travel times for individual riders.

Calculation of the measure is done in a similar way as that for fixed-route transit as described in Chapter 3. To determine the difference in travel time, both the DRT travel time and auto travel time need to be calculated.

To calculate DRT travel time, select a sample of about 10 to 15 origin and destination pairs, reflecting various neighborhoods throughout the community or service area and common destinations, perhaps a frequented shopping mall and major medical facility. With actual operating data on trip travel times from driver manifests, dispatcher records, or Mobile Data Terminals (MDTs) if available, calculate average travel times for a sample of users between the selected origin-destination pairs.

For auto travel time, it is suggested that the manual method described in Chapter 3 be employed. This straightforward method involves simply driving the main route between the selected origin-destination pairs. Any auto access time at the origin or destination end must also be added into the auto travel time to ensure measurement of door-to-door travel time. This access time is assumed to be 3 minutes.

With the average travel times for both DRT and auto between the selected locations, the next step involves calculating the time difference between the two modes for each origin-destination pair. Then, average the travel time differences to compute the average travel time difference between DRT and private auto. Use this average time difference to determine the LOS as indicated in Exhibit 3-36.

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CHAPTER 6. EXAMPLE PROBLEMS

1. Service availability (frequency, hours of service, service coverage—GIS method)
2. Service coverage (manual method)
3. Passenger loading
4. Reliability
5. Transit-auto travel time
6. Service coverage (detailed method)
7. Demand-responsive transit

Example Problem 1

The Situation

Riverbank, population 23,000, is an outer suburb of Anytown. The city is currently in the process of updating its long-range transportation plan and expects to grow significantly in the future. As part of this process, Riverbank wishes to evaluate the quality of existing transit service from an availability perspective and also to compare the location of transit service with where housing and jobs are planned 20 years from now. By doing so, Riverbank hopes to better coordinate its planning with that of the regional transit agency that serves this region of 1.5 million people.

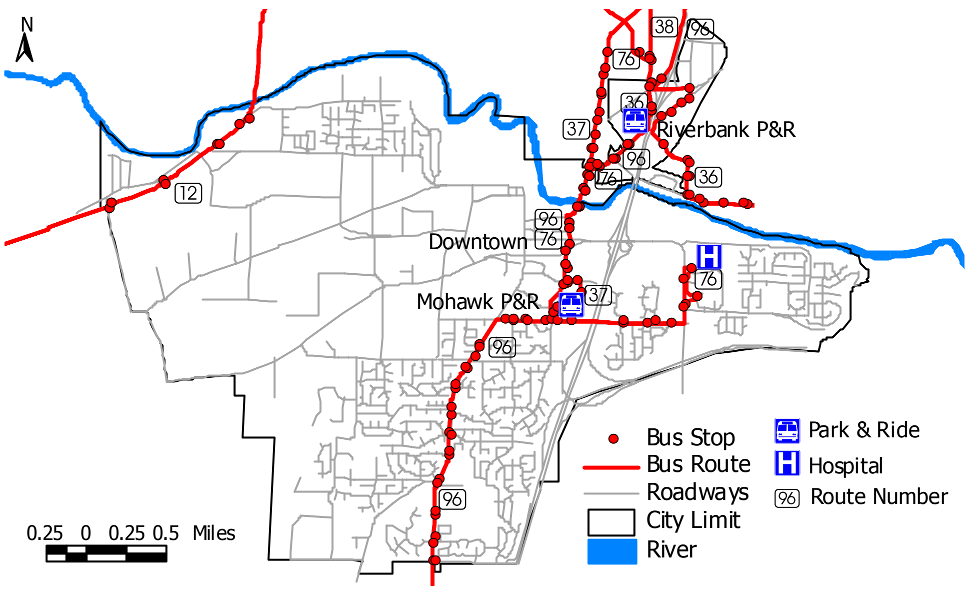
The Questions

1. What is the frequency LOS for trips within the city and to major destinations outside the city?
2. What is the hours of service LOS within the city?
3. What is the service coverage LOS now, and what will it be 20 years from now with no changes to the current route structure?

The Facts

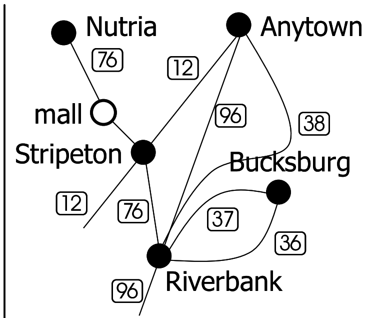
Exhibit 3-37 provides a map of the city, showing the location of bus routes and stops. Major barriers to travel within the city include two freeways and a river, as shown on the map.

Exhibit 3-37
City Map



The following routes serve the city:

- *Route 12* provides all-day service north to the inner suburb of Stripeton, where it connects with Route 76, and continues north to downtown Anytown, where connections can be made to the regional light rail system.
- *Route 36* provides service from the Riverbank park-and-ride to downtown Bucksburg. It only runs every 2 hours during the midday. It has a timed transfer with Route 76 at the park-and-ride.
- *Route 37* provides service from the Mohawk park-and-ride through downtown Riverbank and continues east to downtown Bucksburg. It only



runs every 2 hours during the midday. Between Route 37 and the combination of Routes 36 and 76, it is possible to travel midday between downtown Riverbank and downtown Bucksburg once per hour. During the a.m. peak period, Routes 36 and 37 run every 30 minutes each, but depart and arrive within 3 minutes of each other.

- *Route 38* provides peak hour service to areas north of Bucksburg, continuing to downtown Anytown.
- *Route 76* is a cross-region route that provides service into the evening. It serves the hospital, downtown, and both park-and-rides. It continues to Stripeton (connecting with Route 12), a regional shopping mall, and the inner suburb of Nutria, where it connects with the regional light rail system. During midday hours, the only connection between downtown Riverbank and downtown Anytown is the combination of Routes 76 and 12.
- *Route 96* provides frequent peak hour service between the Mohawk park-and-ride, downtown Riverbank, and the Riverbank park-and-ride, and then travels non-stop on a freeway to downtown Anytown. Every other trip begins just south of Riverbank.

Travel times to downtown Bucksburg are similar via Routes 36 and 37. Travel times from the Riverbank park-and-ride to downtown Anytown are 27 minutes via Route 96 and 50 minutes via the combination of Routes 76 and 12. Because of the considerable difference in travel times and the frequency of service, travelers to Anytown only use Route 96 during peak hours. During the evening, reverse-commute travelers to Anytown will use either the combination of Routes 76 and 12, or Route 96, depending on which will get them to their destination sooner.

Exhibit 3-38 gives the times of the first and last departures from the city for each route and the frequencies of each route from Riverbank for different time periods.

Exhibit 3-38
Bus Route Schedule Data

			Headway (min)				
Route	**First Trip**	**Last Trip**	**AM Peak**	**Midday**	**PM Peak**	**Evening**	**Night**
12	5:09 am	11:38 pm	10	15	10	30	60
36	5:54 am	6:29 pm	30	120	30	--	--
37	6:58 am	5:06 pm	30	120	40	--	--
38	5:59 am	5:34 pm	30	--	30	--	--
76	5:48 am	9:42 pm	30	30	30	60	--
96*	5:20 am	8:34 pm	7-8	--	7-8	60	--
96	5:51 am	8:26 pm	15	--	15	60	--

*from Mohawk park-and-ride north
-- = no service, AM peak = first trip to 9:00 am, midday = 9:00 am to 4:00 pm, PM peak = 4:00 pm to 6:00 pm, evening = 6:00 pm to 9:30 pm, night = after 9:30 pm

Exhibit 3-39 shows the locations of the transportation analysis zones (TAZs) covering Riverbank, which were obtained from the regional transportation planning model. Exhibit 3-40 provides year 2000 and year 2020 household and employment numbers for each TAZ, along with their areas.

Exhibit 3-39
TAZ Locations

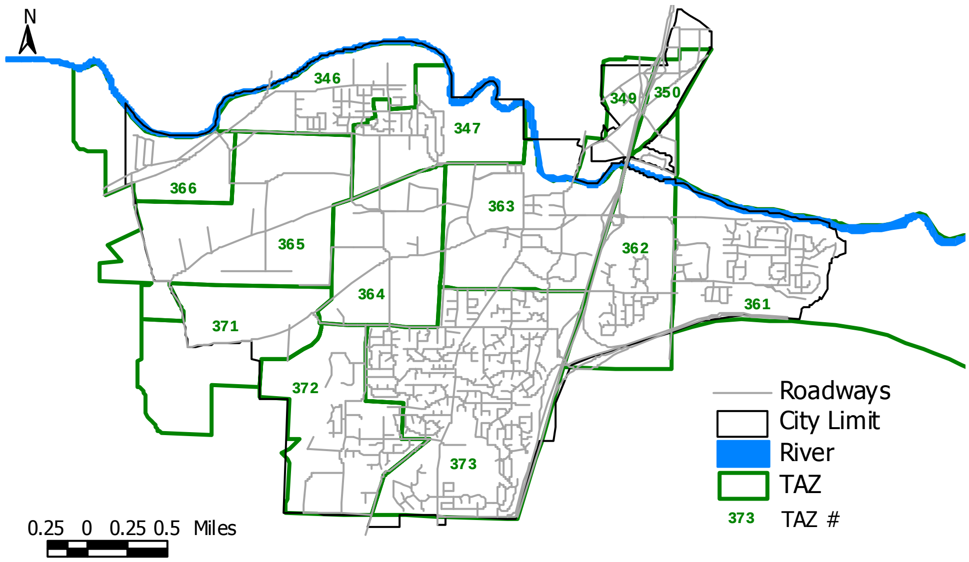


Exhibit 3-40
Population and Employment Data

TAZ	Area (acres)	Year 2000 HH	Year 2000 Jobs	Year 2020 HH	Year 2020 Jobs
346	331.9	506	58	990	676
347	362.3	334	365	1,199	1,204
349	143.9	88	1,346	216	1,524
350	90.8	9	1,203	27	1,415
361	1,203.6	938	472	1,593	844
362	462.8	1,391	1,151	1,864	1,595
363	549.0	854	5,112	2,291	7,572
364	432.0	181	3,022	181	4,373
365	747.3	19	1,518	19	5,361
366	334.4	154	205	516	905
371	500.1	9	375	17	1,344
372	505.0	180	885	826	1,569
373	1,008.3	2,582	580	2,991	891

NOTE: HH = households

Outline of Solution

Service Frequency

Service frequency LOS is determined between pairs of locations. For each pair, determine how often during 1 hour one can make a trip between those locations. The data provided give headways for each route; if a trip requires taking more than one route, the longest headway will control how often a trip can be made. (For example, if the first bus runs every 15 minutes, but connects to a bus that runs every 60 minutes, one can only arrive at the destination once per hour.) Similarly, if there is a choice of more than one set of routes to make a trip, all the possible choices should be looked at in combination (however, remember that departures within 3 minutes of each other are counted as a single opportunity to make a trip).

Hours of Service

Hours of service LOS is determined for individual routes or combinations of routes using the same street. For routes that provide service at least once per hour throughout the day, hours of service will be based on the time of the first and last departures. For routes that operate peak hours only, or have longer-than-hourly service during parts of the day, only those hours where service is provided at least once per hour will be counted.

Service Coverage

Service coverage LOS requires three basic steps: (1) determining the area served by the city's bus routes, (2) determining which portions of the city are "transit-supportive," and (3) determining how much of the TSAs are served by transit.

Solution

Service Frequency

For the purposes of this example, use the trip origins and destinations listed below and evaluate LOS for the a.m. peak and midday hours. A long-range transportation plan would likely look at a greater variety of origins and destinations, as well as other time periods, such as nights and weekends.

Origins

- Downtown Riverbank
- Southern Riverbank (along Route 96 south of the Mohawk park-and-ride)
- Northwestern Riverbank (along Route 12)

Destinations

- Downtown Riverbank
- Hospital
- Downtown Bucksburg
- Downtown Anytown
- Regional mall

From downtown Riverbank during the a.m. peak period, service to the hospital is provided every 30 minutes via Route 76 (LOS "D"), to Anytown every 7 to 8 minutes via Route 96 (LOS "A"), and to the regional mall every 30 minutes via Route 76 (LOS "D"). Travelers to downtown Bucksburg have a choice of routes, but since they leave within 3 minutes of each other, a trip can only be made once every 30 minutes regardless of the route chosen (LOS "D").

From southern Riverbank during the a.m. peak, Route 96 runs every 15 minutes to downtown Riverbank and downtown Anytown (LOS "C"). To reach the other destinations, travelers must transfer to routes that run every 30 minutes; thus, those trips can only be made every 30 minutes (LOS "D").

From northwest Riverbank, Route 12 runs every 10 minutes during the a.m. peak to downtown Riverbank (LOS "B"). Travel to downtown Riverbank, the hospital, and the regional mall requires a transfer to Route 76, which only runs every 30 minutes (LOS "D"). Travel to Bucksburg requires two transfers, with the longest headway involved in the trip being 30 minutes (LOS "D").

Exhibit 3-41 summarizes the results for midday. There is no midday service in the southern portion of Riverbank, thus the LOS from that area is "F" during the midday. Although the individual routes connecting Riverbank to Bucksburg run every 2 hours during the midday, they are scheduled so that a trip is possible once per hour using one route or the other. Travel from northwest Riverbank to Bucksburg involves travel on Route 12 (15-minute service), Route 76 (30-minute service), and Routes 36 or 37 (combined 60-minute service). The longest headway involved in the trip is 60 minutes, thus the LOS for the entire trip is "E."

Exhibit 3-41
Midday Service Frequency LOS Results

Origins	Downtown Riverbank	Hospital	Destinations Downtown Bucksburg	Downtown Anytown	Regional Mall
Downtown	NA	30/LOS D	60/LOS E	30/LOS D	30/LOS D
South	--/LOS F	--/LOS F	--/LOS F	--/LOS F	--/LOS F
Northwest	30/LOS D	30/LOS D	60/LOS E	15/LOS C	30/LOS D

NOTE: headways in minutes.
NA = not applicable, -- = no service

Hours of Service

Hours of service can be determined by route. However, for a city with a simple route structure such as Riverbank, the process can be shortened by dividing the city into areas that receive similar amounts of service. For Riverbank, these are:

- The area between the park-and-rides, including downtown, which are served by Routes 37, 76, and all Route 96 runs;
- The hospital area, which is served only by Route 76;
- Southern Riverbank, which is served only by some Route 96 runs;
- Northwest Riverbank, which is served only by Route 12; and
- The northeast corner of Riverbank, across the freeway from the park-and-ride, which is served only by Route 36.

The downtown area receives service at least hourly throughout the day, from 5:20 a.m. (the first Route 96 run) to 9:42 p.m. (the last Route 76 run). After converting these times to a 24-hour clock, subtracting 0520h from 2142h results in a difference of 16 hours, 22 minutes. Adding 1 hour to the result and dropping the fractional hour gives a total hours of service of 17 hours, or LOS "B."

Southern Riverbank does not have service midday. Hourly-or-better service is provided between 5:51 a.m. and 9:00 a.m. (4 hours of service), and between 4:00 p.m. and 8:26 p.m. (5 hours of service), for a total of 9 hours of service, or LOS "E".

Although northeast Riverbank has midday service, it is only provided every 2 hours, and thus does not count toward hours of service. Hourly-or-better service is provided between 5:54 a.m. and 9:00 a.m. (4 hours of service), and between 4:00 pm. and 6:00 p.m. (3 hours of service), for a total of 7 hours of service, or LOS "E."

Similarly, the hospital area receives 17 hours of service (LOS "B"), while northwest Riverbank receives 19 hours of service (LOS "A"). Exhibit 3-42 shows these results in the form of a map.

Service Coverage

The GIS planning method of calculating service coverage will be used for this example. For an example that applies the manual method, see Example Problem 2. For an example that applies the detailed method, see Example Problem 5.

As Riverbank only receives bus service, a 0.25-mile (400-m) buffer is created around each bus stop, representing the area served by each bus stop. If desired, these buffers can be created by route, so that the resulting map can also be used to display hours of service LOS. The buffers should be clipped in areas where service coverage would not extend across a barrier. In the case of Riverbank, the river and the two freeways form barriers which need to be considered. The results are shown in Exhibit 3-42 (for clarity, areas served by transit that are outside the city limits are not shown). All shaded areas are considered to receive service; the darkness of the shading indicates the hours of service LOS provided to each area, as calculated from the previous step.

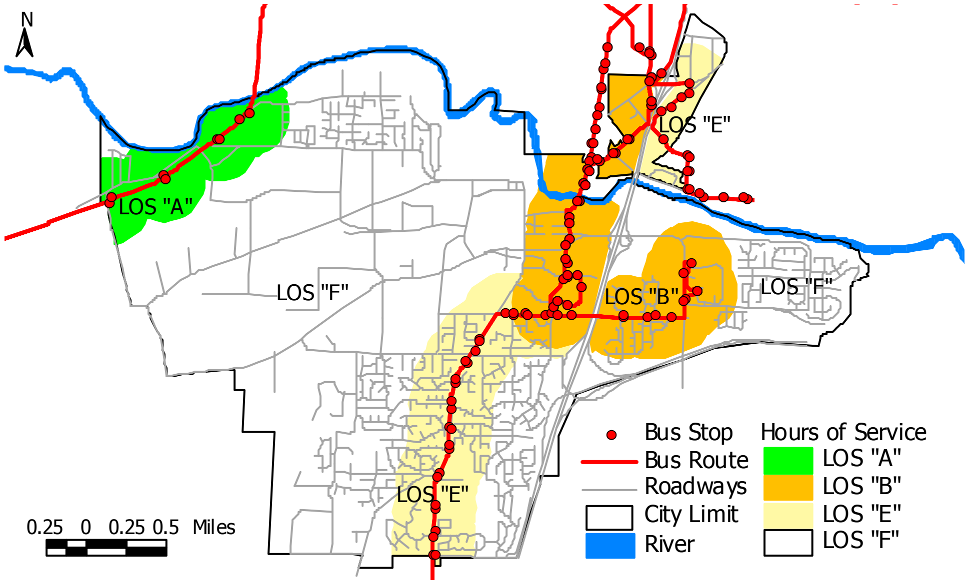


Exhibit 3-42
Service Coverage Area and Hours of Service LOS

All shaded areas are considered to be served by transit. Areas served by transit outside the city limits are not shown.

Next, each TAZ is evaluated to determine whether it meets the criteria for being "transit-supportive" (a household density of 3 households or more per acre or a job density of 4 jobs or more per acre). Household density is calculated by dividing the TAZ's households (given in Exhibit 3-40) by its area in acres. Job density is calculated similarly. For example, the year 2000 household density of TAZ 362 is 1,391 households, divided by 482.8 acres, or 2.88 households per acre. This is slightly below the criterion for TAZ 362 to be a TSA. Results for all TAZs are given in Exhibit 3-43.

Exhibit 3-43
Household and Job Densities

	Year 2000			Year 2020		
TAZ	HH Density	Job Density	TSA?	HH Density	Job Density	TSA?
346	1.52	0.17		2.98	2.04	
347	0.92	3.31		1.01	3.32	
349	0.61	9.35	✓	1.50	10.59	✓
350	0.10	13.25	✓	0.30	15.58	✓
361	0.78	0.39		1.32	0.70	
362	2.88	2.38		3.86	3.30	✓
363	1.56	9.31	✓	4.17	13.79	✓
364	0.42	7.00	✓	0.42	10.12	✓
365	0.03	2.03		0.03	7.17	✓
366	2.17	0.61		1.54	2.71	
371	0.02	0.75		0.03	2.69	
372	0.36	1.75		1.64	3.11	
373	2.56	0.58		2.97	0.88	

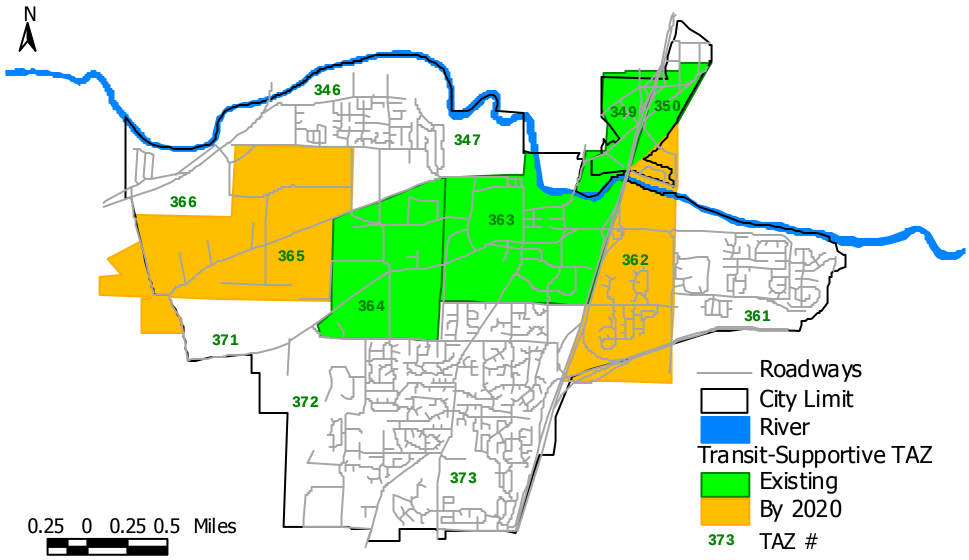
NOTE: HH = households, TSA = transit-supportive area
Densities in households/acre and jobs/acre.

A local transportation plan might wish to go into more detail to identify potential TSAs. For example, TAZs could be subdivided to remove undeveloped areas. This would have the effect of increasing the density in the developed areas. Also, TAZs could be subdivided based on zoning or comprehensive plan designations, so that households were only assigned to areas zoned for residential development, for example. A further refinement would be to assign more households to areas designated for multi-family housing. Any of these steps would provide greater understanding of the sections of the city that could support hourly transit service, and it is likely that TAZs 346 and 373 would turn out to be transit-supportive in the future if these steps were taken. However, for simplicity, this example will use the basic planning methodology outlined in Chapter 3.

A more detailed analysis could look at where particular land use types are located within a TAZ.

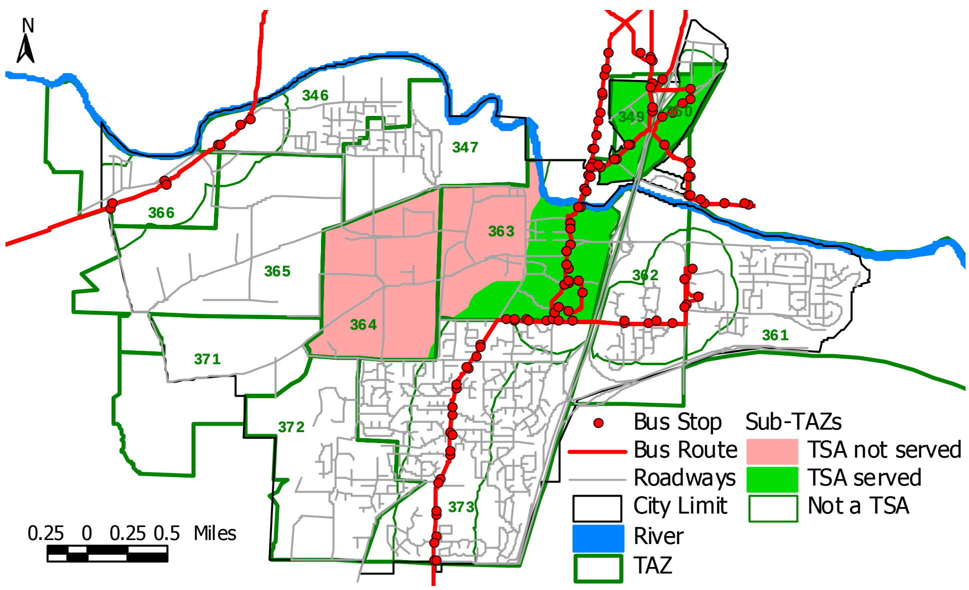
Exhibit 3-44 shows the locations of the transit-supportive TAZs.

Exhibit 3-44
Transit-Supportive TAZs



Next, the buffers indicating the areas receiving transit service are intersected with the TAZs. The result is that TAZs are subdivided into smaller sub-TAZs, each of which is either entirely within the transit service coverage area or entirely outside the transit service coverage area. Exhibit 3-45 shows the results of this process for Riverbank, for existing conditions. Of the four transit-supportive TAZs, all of TAZs 349 and 350 are served, about one-half of TAZ 363 is served, and almost none of TAZ 364 is served.

Exhibit 3-45
Year 2000 Transit-Supportive Areas Served



NOTE: TAZ = transportation analysis zone, TSA = transit-supportive area

Finally, the area of the portion of the TSAs that are served is divided into the total area of the TSAs. The resulting percentage is used to calculate the service coverage LOS. In this case, from Exhibit 3-46, dividing the area served (540.1 acres) into the total TSA (1,215.7 acres) results in 44%, or LOS "F."

Transit-Supportive TAZ	Area (acres)	Area Served (acres)
349	143.9	143.9
350	90.8	90.8
363	549.0	302.6
364	432.0	2.8
Total	1,215.7	540.1

Exhibit 3-46
Service Coverage LOS Calculation

The Results

The service provided to Riverbank is not unusual for a low-density suburb: as most of the residential areas cannot support hourly transit service, much of the service is focused around park-and-ride lots, serving the commuter market. During peak hours, the park-and-ride and downtown Riverbank areas receive excellent service into downtown Anytown, but receive fairly infrequent service to other destinations. Those residential areas that do receive service generally only have service during peak periods; most residential areas cannot make midday transit trips to downtown Riverbank, the hospital, or other destinations.

The service coverage analysis indicates that a large area with sufficient employees to support transit service is not receiving service, and that this area will be even bigger by the year 2020.

Example Problem 2

The Situation

As part of an overall review of its service, a transit agency wants to evaluate its service coverage area. The agency provides fixed-route bus service to a city of 125,000 people. Its service area includes two universities, a community college, and numerous government offices scattered about the city. Although the agency has access to regional transportation planning model data maintained by the local metropolitan planning organization (MPO), it does not have access to GIS software.

The Questions

Where are the city's TSAs, and how well are they being served?

The Facts

- The MPO's model contains population and employment figures at the TAZ level. The TAZ map is available in an electronic form that allows the areas of each TAZ to be calculated.
- Census data for the area indicate an average household size of 2.5 people.

Outline of Solution

Under the manual calculation method, the TSA is identified first. (See Example Problem 1 for an example using GIS software.) Next, the coverage area of the routes serving the transit-supportive TAZs is identified. Third, the approximate percentage of each transit-supportive TAZ served by transit is identified. Finally, the percentage of the total TSA served by transit is calculated to determine LOS.

Steps

1. Develop a spreadsheet from the data used for the transportation model, listing population, jobs, and area for each TAZ. Convert population to households by dividing by the average household size, in this case, 2.5. Calculate household density for each TAZ by dividing the number of households by the TAZ's area (in acres); calculate job density similarly. A TAZ is transit-supportive if the household density is at least 3 households per acre, or the job density is at least 4 jobs per acre. Exhibit 3-47 illustrates this process for two TAZs:

Exhibit 3-47
Example Transit-Supportive Area Determination

TAZ	Pop	Jobs	Area (ft^2)	House-holds	Area (acres)	HH Density	Job Density	TSA?
255	1,134	308	10,941,788	453.6	251.2	1.81	1.23	
399	345	852	5,355,176	138.0	122.9	1.12	6.93	✓

NOTE: TAZ = transportation analysis zone, Pop = population, HH = households

In this example, TAZ 255 is not transit-supportive, but TAZ 399 is. Exhibit 3-48 illustrates the locations of all of the transit-supportive TAZs identified through this process. There are 174 transit-supportive TAZs in all.

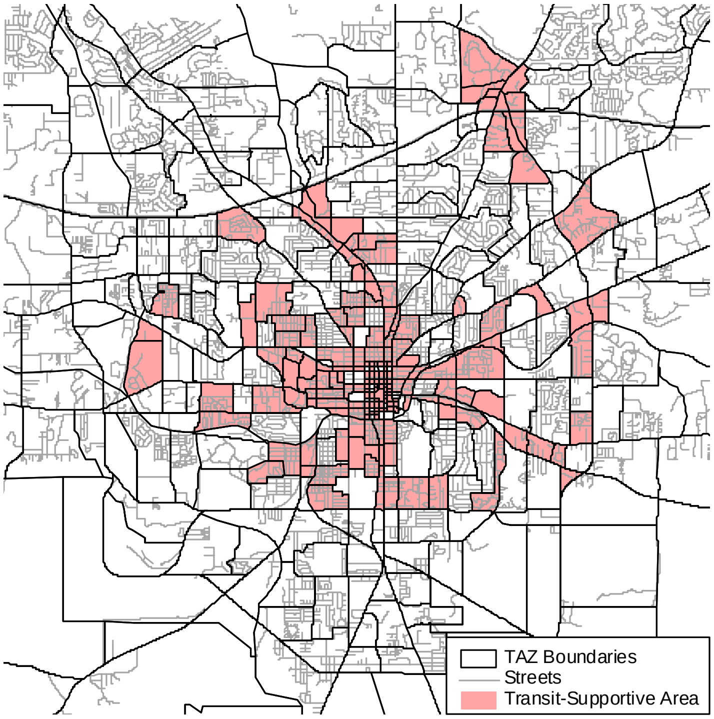


Exhibit 3-48
Transit-Supportive Area Locations

2. For the transit-supportive TAZs identified in step 1, draw the location of the bus routes serving those TAZs, and draw 0.25-mile (400-m) buffers around each route, excluding any areas known not to have pedestrian access. This process is illustrated in Exhibit 3-49.

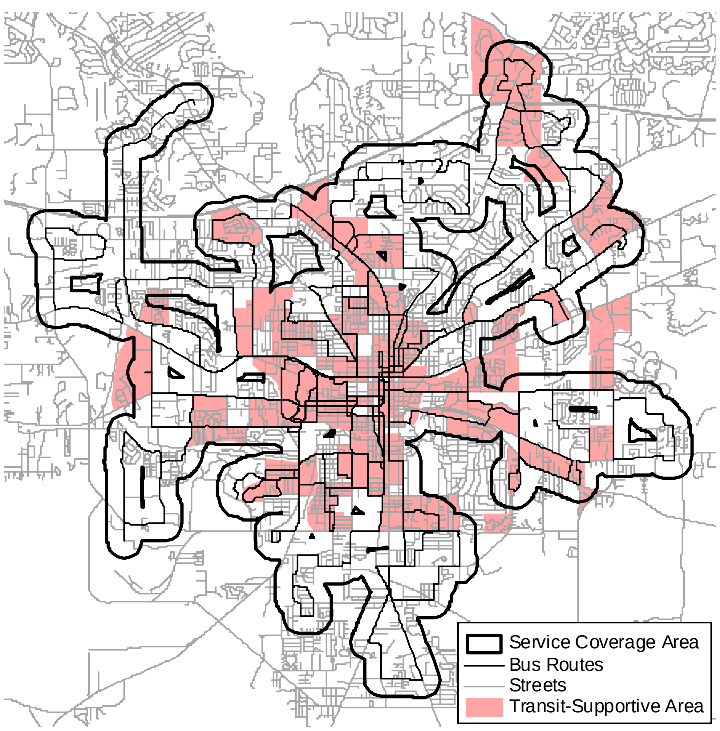
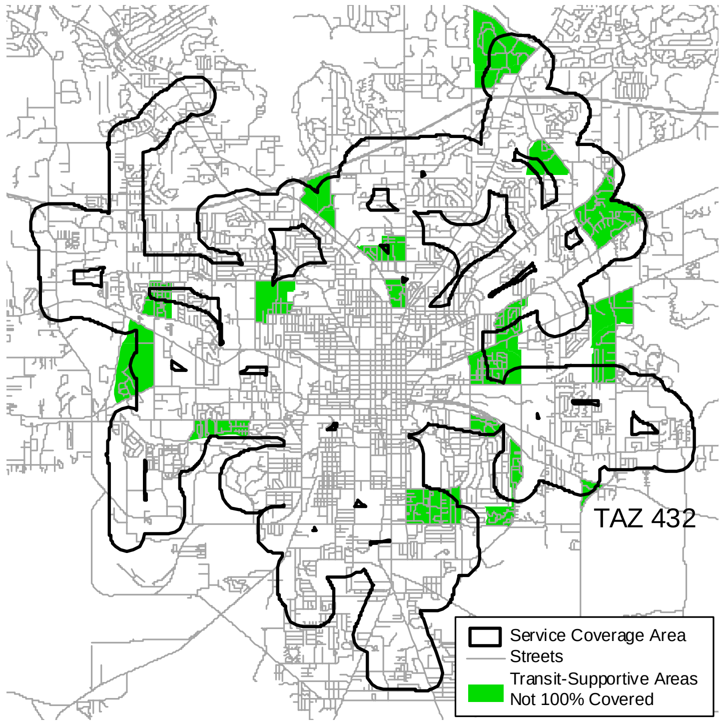


Exhibit 3-49
Bus Route Buffers

3. Twenty-four of the 174 transit-supportive TAZs are only partially served by transit, as depicted in Exhibit 3-50. Estimate the percentage of the area of each of these TAZs that is served by transit, to within 10%. For example, TAZ 432 is about 50% served by transit.

Exhibit 3-50
Partially Served TAZs



4. Divide the TSA served by transit by the total area of the TSAs to determine the percentage of the TSA served, and the resulting service coverage LOS.

The Results

The total TSA is 12.6 square miles, and 10.8 square miles of it is served by transit. As a result, 86% of this system's TSA is served, corresponding to LOS "B." The portions of the city that can support at least hourly bus service receive, for the most part, at least some service during the day. For policy reasons or simply to connect two higher-density areas, most agencies will serve a considerably larger area than the TSA.

Example Problem 3

The Situation

After receiving customer complaints about excessive crowding on one of its heavily used bus lines, a transit agency reviews its automatic passenger counter (APC) data from the previous month to determine whether its passenger loading policy is being exceeded. Not all of the agency's buses are APC-equipped; instead, buses with APCs are assigned such that each run is sampled at least once per month.

The Question

Is the agency loading policy being exceeded on a regular basis?

The Facts

- During the a.m. peak hour (7:00 to 8:00 a.m.) in the inbound direction, 13 buses are scheduled. Scheduled headways range from 3 to 6 minutes (an average of 4 to 5 minutes), and each run is scheduled to take 47 minutes from beginning to end.
- The agency's loading standard for peak periods is that no bus should exceed its maximum schedule load (LOS "E").
- The buses assigned to this line are 40 feet long and 8 feet wide, with single-channel front and rear doors, and 41 seats (20 transverse, 21 longitudinal).
- The data available for the analysis consist of 13 sets of weekday boardings and alightings by stop, one set for each inbound trip made during the a.m. peak hour during the month in question.

Outline of Solution

LOS for standees is based on the area available to each standing passenger. Dividing this area by the threshold between LOS "E" and "F" (2.2 ft^2 per passenger, from Exhibit 3-26) gives the maximum number of standees allowed by policy.

One can determine the passenger load on each bus from the APC data. This load is the load arriving at the stop, minus the count of passengers getting off, plus the count of passengers getting on. By repeating this process for all stops, one can determine for each sampled run whether the maximum number of standees was exceeded at any given stop. However, because the data represent only one weekday trip made on a given run during the month, one cannot tell whether or not each sampled run is representative of typical conditions for that run.

As an alternative, one can average the results together for the peak hour, and then apply an appropriate peak hour factor to determine whether the maximum number of standees was exceeded during the peak 15 minutes (i.e., the most crowded 3 or 4 buses out of the 13 that operate during the hour).

Steps

1. First, determine the maximum number of standees at LOS "E," given the interior configuration of the agency's buses. The gross interior floor area is estimated by subtracting 8.5 feet from the bus length (an allowance for the engine compartment and the operator's area), and multiplying the result by the bus width. In this case, (40-8.5)*8 is 252 square feet.

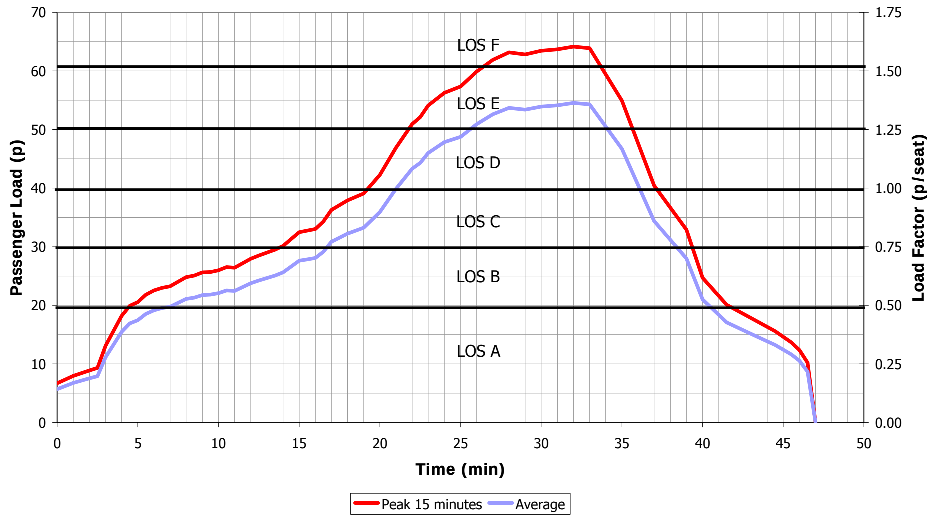
   Next, subtract the area occupied by seats and other objects to determine the net interior floor area available for standees:

Gross interior floor area	252.0 square feet
20 transverse seats at 5.4 square feet each	-108.0 square feet
21 longitudinal seats at 4.3 square feet each	-90.3 square feet
single-channel rear door at 8.6 square feet per channel	-8.6 square feet
Net interior floor area	45.1 square feet

Dividing the net interior floor area (45.1 ft²) by the minimum space per passenger at LOS "E" (2.2 ft²/p) gives the maximum number of standees for a maximum schedule load: 20 passengers. Adding this result to the number of seats on the bus gives the maximum schedule load: 61 passengers.

2. The average load at each stop, calculated from the APC data, is plotted against the scheduled departure time from each stop. Plotting load against time helps to visualize how long particular loading conditions occur. Exhibit 3-51 shows the results. As can be seen from the lower curve, an average of 55 passengers are carried at the maximum load section, meeting the standard. However, this result assumes that all passengers are evenly distributed among the buses throughout the hour, which is unlikely to happen.

Exhibit 3-51
Passenger Load Example



Peak hour factors are discussed in Part 4, Bus Transit Capacity.

3. To estimate the average load during the peak 15 minutes, divide the average load for the hour by an appropriate peak hour factor (PHF). Peak hour factors for buses typically range from 0.60 to 0.95, with 0.75 recommended as a default in the absence of other information. However, because the line's schedule already reflects some variations in loading (i.e., the scheduled headways vary from 3 to 6 minutes), a higher PHF is appropriate. Using a PHF of 0.85 produces the upper curve on the graph. It can be seen that the agency loading standard will be exceeded for an average of 6 to 7 minutes at a time on the most heavily loaded three or four buses during the hour.

The Results

Based on this analysis, it appears likely that the agency's loading standard is exceeded on some runs during the a.m. peak hour. As the standard is not exceeded by much, adjusting the headways to even out the loads between buses (thus raising the PHF) might be sufficient to meet the standard. However, some variation in loads would always be expected, resulting from variations in running times due to traffic and other factors. The graph also indicates that standees are present for 15 minutes on average (from the threshold between LOS "C" and "D") and that the first standee would often have to stand for at least 12 minutes before a substantial number of passengers began to get off the bus.

Example Problem 4

The Situation

As part of its 5-year planning process, a transit agency adopted a customer charter expressing a commitment to improving the quality of service provided to its customers. One of the agency's adopted goals is to improve the reliability of the service it provides. As a first step, the agency is reviewing the on-time performance of some of its more popular routes to determine how good a job the agency is currently doing and to determine whether there are areas where it can work to improve performance. This example looks at the evaluation conducted at one timepoint along one of these routes.

The Questions

- What is the on-time performance LOS currently provided, as an average for the day, and during the a.m. peak, midday, and p.m. peak periods?
- Some afternoon buses are scheduled at 10-minute headways, between 3:52 p.m. and 5:02 p.m. What is the headway adherence LOS during that period?
- If needed, what are some areas of improvement to focus on?

The Facts

- The a.m. peak is defined for this route as departures prior to 9:00 a.m., midday is defined as departures from 9:00 a.m. to 3:30 p.m., and the p.m. peak is defined as departures after 3:30 p.m.
- Exhibit 3-52 shows scheduled and actual departure times on the day that data were collected:

Exhibit 3-52
Bus Departure Time Data

A.M. Peak		Midday		P.M. Peak	
Scheduled	**Actual**	**Scheduled**	**Actual**	**Scheduled**	**Actual**
5:06 am	5:06 am	9:06 am	9:06 am	3:52 pm	3:52 pm
5:37 am	5:38 am	9:22 am	9:21 am	4:02 pm	4:05 pm
5:52 am	5:52 am	9:38 am	9:38 am	4:12 pm	4:13 pm
6:06 am	6:07 am	9:54 am	9:56 am	4:22 pm	4:29 pm
6:20 am	6:20 am	10:09 am	10:09 am	4:32 pm	4:32 pm
6:32 am	6:34 am	10:24 am	10:25 am	4:42 pm	4:47 pm
6:47 am	6:48 am	10:39 am	10:39 am	4:52 pm	4:48 pm
7:01 am	7:04 am	10:57 am	10:59 am	5:02 pm	5:02 pm
7:16 am	7:22 am	11:12 am	11:11 am	5:13 pm	5:15 pm
7:32 am	7:38 am	11:25 am	11:25 am	5:26 pm	5:30 pm
7:47 am	7:51 am	11:40 am	11:40 am	5:41 pm	5:46 pm
8:02 am	8:06 am	11:54 am	11:52 am	5:57 pm	6:01 pm
8:17 am	8:20 am	12:09 pm	12:09 pm	6:15 pm	6:17 pm
8:33 am	8:35 am	12:24 pm	12:24 pm	6:33 pm	6:36 pm
8:50 am	8:50 am	12:39 pm	12:40 pm	6:49 pm	6:50 pm
		12:54 pm	12:53 pm	7:06 pm	7:08 pm
		1:10 pm	1:11 pm	7:21 pm	7:23 pm
		1:26 pm	1:25 pm	7:36 pm	7:36 pm
		1:42 pm	1:40 pm		
		1:57 pm	1:58 pm		
		2:12 pm	2:12 pm		
		2:27 pm	2:25 pm		
		2:39 pm	2:41 pm		
		2:49 pm	2:52 pm		
		3:01 pm	3:02 pm		
		3:15 pm	3:15 pm		
		3:30 pm	3:31 pm		

Outline of Solution

A bus is considered "on-time" if it departs no more than 5 minutes after the scheduled time and is not early. By comparing each departure's scheduled and actual departure times, each departure can be classified as "early" (actual departure time before the schedule departure time), "on-time" (actual departure is 0 to 5 minutes after the scheduled time), or "late" (actual departure is more than 5 minutes after the scheduled time). Dividing the number of on-time departures by the total number of departures gives the on-time percentage, which in turn gives the LOS.

Headway adherence LOS will be calculated for the departures between 3:52 and 5:02 p.m. The process here is to first calculate the headway deviation for each departure (the number of minutes the actual headway deviated from the scheduled headway, which is 10 minutes). Next, the coefficient of variation of headways is calculated and the corresponding LOS determined. (Because these frequent departures are scheduled, include them in both the on-time percentage calculation and the headway adherence calculation.)

Steps

1. For each departure, determine whether it is on-time, early, or late. For example, the scheduled 6:47 a.m. departure actually left at 6:48 p.m., which is considered on-time; the scheduled 7:32 a.m. departure left at 7:38 a.m., which is considered late; and the scheduled 1:42 p.m. departure left at 1:40 p.m., which is considered early.

   During the a.m. peak period, the scheduled 7:16 a.m. and 7:32 a.m. departures were late, while the other 13 departures were on-time. The corresponding on-time percentage, 13/15, is 87%, or LOS "C."

   During the midday period, the scheduled 9:22 a.m., 11:12 a.m., 11:54 a.m., 12:54 p.m., 1:26 p.m., 1:42 p.m., and 2:27 p.m. departures all left early, while the other 20 departures were on-time. The on-time percentage in this case, 20/27, is 74%, or LOS "F."

   During the p.m. peak period, the scheduled 4:22 p.m. departure was late and the scheduled 4:52 p.m. departure was early, while the other 16 departures were on time. The corresponding on-time percentage, 16/18, is 89%, or LOS "C." For the day as a whole, 49 of 60 buses were on time (82%), equivalent to LOS "D."

2. The headways between the buses scheduled to depart between 3:52 and 5:02 p.m. are 13, 8, 16, 3, 15, 1, and 14 minutes. The corresponding headway deviations are +3, -2, +6, -7, +5, -9, and +4 minutes. The sum of these values (Σx_i) is 0 and the square of the sum $(\Sigma x_i)^2$ is 0. The sum of the squares of the values (Σx_i^2) is 220 (e.g., $3^2 + (-2)^2 + \ldots + (4)^2$). There are 7 observations, so use the sample standard deviation:

   $$s = \sqrt{\frac{\sum x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}} = \sqrt{\frac{220 - \frac{0}{7}}{6}} = 6.06$$

   The coefficient of variation of headways is the standard deviation divided by the average scheduled headway, 6.06 / 10, or 0.61, equivalent to LOS "E." As can be seen from Exhibit 3-52, several buses arrived bunched together.

The Results

An obvious way to improve on-time performance at this location is to control early running. If the early trips were eliminated, on-time performance for the day would increase to 93%, equivalent to LOS "B." Another area to focus on is maintaining the evenness of the interval between the buses scheduled at 10-minute headways. Because several buses were bunched, it is likely that the lead bus in each case experienced overcrowding, while the following bus had unused capacity.

Example Problem 5

The Situation

As part of a regional study of traffic congestion, the Anytown MPO wishes to compare existing travel times by transit and auto to help determine where transit service improvements or transit priority measures may be needed to help make transit service more competitive with the automobile.

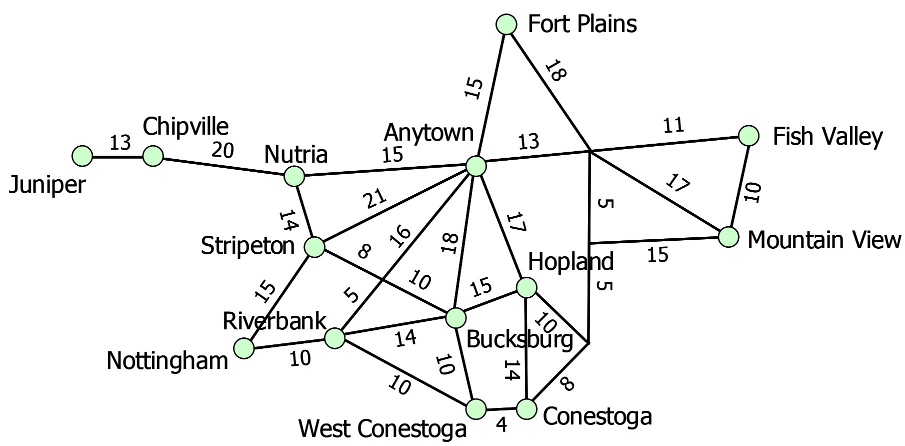
The Question

What are comparative travel times by transit and auto between city centers in the region during the a.m. peak hour, and what is the corresponding LOS?

The Facts

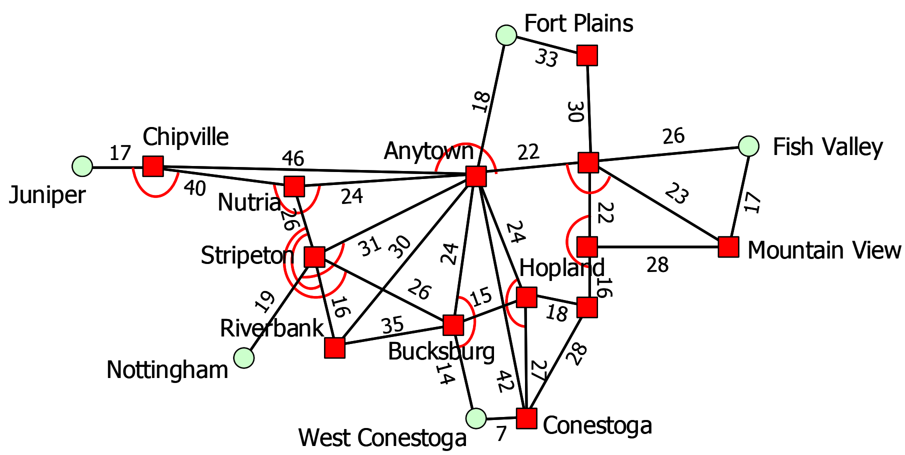
Travel time data for key regional roadways were collected by driving each of the links several times during the a.m. peak hour. The average results of these travel time runs are shown in Exhibit 3-53, giving peak direction travel times in minutes.

Exhibit 3-53
Auto Travel Times



Current scheduled peak direction transit travel times are shown in Exhibit 3-54. Transfers occur at locations marked by squares. "Bypasses" shown on the map indicate trips where no transfer needs to be made.

Exhibit 3-54
Transit Travel Times



The following additional information is known:

- Passengers average 3 minutes of walking at each end of their trip.
- Wait time for transit is assumed to be 5 minutes at the start of a trip.
- Each transfer is assumed to add 10 minutes to a trip.
- Auto trips to Anytown add 5 minutes on average for parking in garages, and 3 minutes average walk time from garages to offices.
- Plentiful free parking is available at all work locations outside Anytown.
- Congestion in central Nutria adds 5 minutes to access the freeway system from Nutria by car.

Outline of Solution

Door-to-door travel times will be calculated between each location, first by automobile, and then by transit. These times include actual in-vehicle time, from the maps on the preceding page, plus the adjustments listed above for access to and from each mode. The transit-auto travel time difference will be calculated by subtracting the auto time from the transit time, and the LOS determined from the result.

Steps

1. Determine the door-to-door peak direction auto travel time between each pair of locations. For example, from Chipville to Anytown, this time includes 35 minutes of in-vehicle time (tracing a path from the map), plus 5 minutes parking time, plus 3 minutes walking time, for a total of 43 minutes. The other results, in minutes are listed below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	28	56	38	43	26	25	39	32	39	29	29	23	36
Nutria		38	50	25	37	37	46	44	34	19	32	35	42
Jun			78	13	65	65	74	72	62	47	60	63	70
Mtn V				65	42	30	28	10	52	51	42	35	32
Chip					52	52	61	59	49	34	47	50	57
Buck						15	14	42	24	18	14	33	10
Hop							14	31	39	33	29	32	18
Con								29	24	27	14	36	4
Fish V									55	45	45	29	33
Not										15	10	46	20
Str											13	36	23
Riv												36	10
Ft P													40

2. Determine the door-to-door peak direction transit travel time between each pair of locations. For example, from Fish Valley to Anytown, this time includes 48 minutes of in-vehicle time (tracing a path from the map), a total of 6 minutes of walking time at both ends of the trip, 5 minutes wait time at the start of the trip, and 10 minutes of transfer time, for a total of 69 minutes. The other results, in minutes, are listed below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	35	84	56	57	35	35	53	69	61	42	41	29	49
Nutria		68	90	51	63	69	76	103	66	37	53	63	83
Jun			129	28	118	118	136	142	133	104	120	112	132
Mtn V				102	90	90	103	28	116	97	96	84	104
Chip					91	91	109	115	116	87	97	85	105
Buck						26	32	103	66	37	46	63	25
Hop							38	103	91	62	71	63	50
Con								121	97	68	77	81	18
Fish V									129	110	109	97	117
Not										30	56	89	90
Str											27	70	61
Riv												69	70
Ft P													77

3. Subtract the auto travel times from the transit travel times. For example, the auto travel time from Chipville to Anytown is 43 minutes, the transit travel time is 57 minutes, and the difference is 14 minutes, equivalent to LO S "B." The results, in minutes and LOS, for all trip combinations are shown below:

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	7	28	18	14	9	10	14	37	22	13	12	6	13
Nutria		30	40	26	26	32	30	59	32	18	21	28	41
Jun			51	15	53	53	62	70	71	57	60	49	62
Mtn V				37	48	60	75	18	64	46	54	49	72
Chip					39	39	48	56	67	53	50	35	48
Buck						11	18	61	42	19	32	30	15
Hop							24	72	52	29	42	31	32
Con								92	73	41	63	45	14
Fish V									74	65	64	68	84
Not										15	46	43	70
Str											14	34	38
Riv												33	60
Ft P													37

	Nutria	Jun	Mtn V	Chip	Buck	Hop	Con	Fish V	Not	Str	Riv	Ft P	W Con
Any	B	C	C	B	B	B	B	D	C	B	B	B	B
Nutria		C	D	C	C	D	C	E	D	C	C	C	D
Jun			E	B	E	E	F	F	F	E	E	E	F
Mtn V				D	E	E	F	C	F	E	E	E	F
Chip					D	D	E	E	F	E	E	D	E
Buck						B	C	F	D	C	D	C	B
Hop							C	F	E	C	D	D	D
Con								F	F	D	F	D	B
Fish V									F	F	F	F	F
Not										B	E	D	F
Str											B	D	D
Riv												D	E
Ft P													D

The Results

The radial route pattern serving Anytown provides good levels of service (LOS "B" or "C") from everywhere within the metro area except Fish Valley. Service between suburbs is generally poor, as is often the case with a radial pattern, although some suburbs (e.g., Nutria) have relatively good service. Because of the high number of transfers involved, transit travel times from Fish Valley are very high compared with the automobile, making transit an unattractive option for potential riders.

Possible service improvements to consider include:

- Provide express service from distant suburbs to Anytown to reduce travel times.
- Expand cross-town routes between suburbs where demand warrants.
- Decrease the number of transfers required or improve timed transfers to reduce the average wait time when transferring between routes.
- Establish transit priority measures on high-volume routes serving Anytown to make travel times even more competitive with the automobile.

Naturally, the potential demand for the service improvements would need to be taken into consideration, along with the cost of those improvements.

Example Problem 6

The Situation

The Marbleton Transit Authority has developed a good working relationship with the City of Marbleton, and the city routinely gives extra priority to public works projects, such as sidewalk and pedestrian crossing improvements that provide transit benefits. The two agencies are currently evaluating Route 29, which runs parallel to an elevated freeway, to see what kinds of improvements, if any, might provide better access to transit.

The Question

What is Route 29's service coverage area, compared with the ideal?

The Facts

Exhibit 3-55 shows a map of the study area. Exhibit 3-56 lists the traffic volumes and geometric characteristics (street width and median type) for the streets used by the route. There are two traffic signals in the area: one at the intersection of Spring Park Road and Spring Glen Road, which has a 90-second cycle length, and one at the intersection of Barnes Road and University Boulevard, which has a 180-second cycle length. All of the streets are undivided, although Barnes Road South has a two-way left-turn lane, so that pedestrians have to cross the equivalent of three lanes. The area is flat, and the senior population forms less than 20% of the total area population.

Exhibit 3-55
Study Area Map

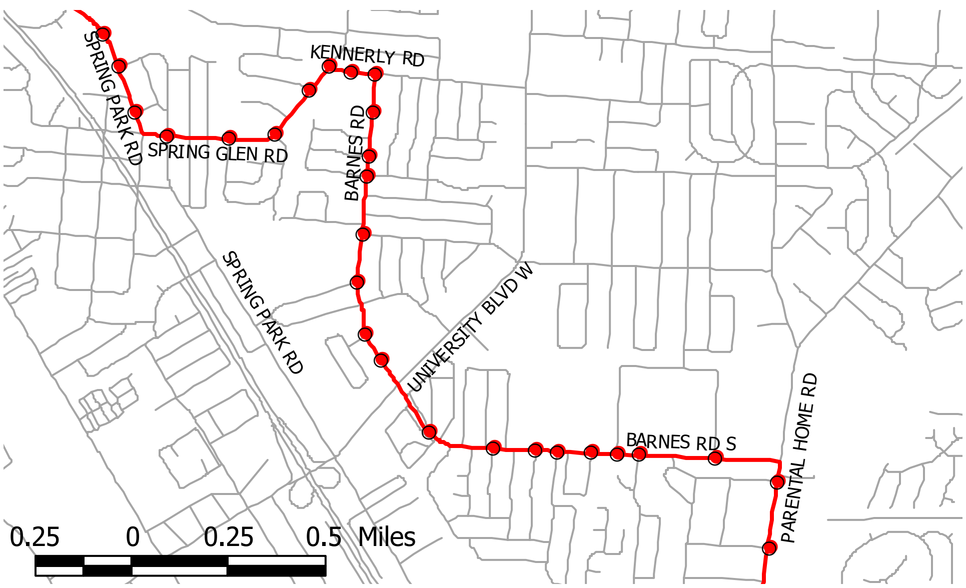


Exhibit 3-56
Street Data

Street Name	Peak Hour Traffic Volume (veh/h)	Street Width (lanes)
Spring Park Road	350	2
Spring Glen Road	1,150	2
Kennerly Road	500	2
Barnes Road North	550	2
Barnes Road South	1,000	3
Parental Home Road	1,300	2

Outline of Solution

The detailed service coverage method will be used to identify the effective area served by each bus stop, accounting for the street pattern, the difficulty pedestrians have crossing streets, and any other applicable factors. The relative contribution of each factor to the reduction in coverage area will be determined. Finally, the size of the reduced service coverage area will be compared with the size of the ideal service coverage area.

Steps

1. The TCQSM uses 0.25 mile as the ideal radius served by a local bus stop. Equation 3-2 will be used to determine the reduction in this radius due to the following four factors: street connectivity factor, grade (terrain), population characteristics, and pedestrian crossing difficulty.
2. Comparing the map of the study area with the street pattern types depicted in Exhibit 3-18, it appears that the street pattern most closely resembles the Type 2 (hybrid) pattern. The street network does not form a grid; yet, there is some connectivity provided and relatively few dead-end streets and culs-de-sac. From Exhibit 3-19, the street connectivity factor for a Type 2 pattern is 0.85.
3. The area is flat, so the grade factor is 1.00.
4. Less than 20% of the area's population is elderly; therefore, the population factor is 1.00.
5. To determine the pedestrian crossing factor, first find out how much delay pedestrians encounter while crossing streets. For example, Barnes Road South has a traffic volume of 1,000 vehicles per hour and a three-lane width. From Exhibit 3-24, the average pedestrian delay is 100 seconds. Subtracting 30 seconds from this result gives the amount of excess pedestrian delay at this location—70 seconds. The results for all unsignalized crossings are listed below:

Street Name	Average Pedestrian Delay (s/ped)	Excess Pedestrian Delay (s/ped)
Spring Park Road	5	0
Spring Glen Road	44	14
Kennerly Road	9	0
Barnes Road North	10	0
Barnes Road South	100	70
Parental Home Road	60	30

For the two signalized intersections, Equation 3-4 should be used. In the absence of other information, we will use an effective green time of 11 seconds (7 seconds of WALK time, plus four seconds of flashing DON'T WALK). At the Spring Park/Spring Glen intersection, the traffic signal cycle length is 90 seconds. Applying this information to Equation 3-4 gives the following average pedestrian delay, in seconds:

$$d_p = \frac{0.5(C-g)^2}{C} = \frac{0.5(90-11)^2}{90} = 35\,\text{s}$$

The excess delay is 30 seconds less, or 5 seconds. Performing the same calculation for the Barnes/University intersection produces an average pedestrian crossing delay of 80 seconds and an excess delay of 50 seconds.

6. Next, we will apply Equation 3-3 to determine the pedestrian crossing factor. Using Barnes Road South as an example, with 70 seconds of excess delay, the pedestrian factor is:

$$f_{px} = \sqrt{\left(-0.0005 d_{ec}^2 - 0.1157 d_{ec} + 100\right)/100}$$

$$f_{px} = \sqrt{\left(-0.0005(70)^2 - 0.1157(70) + 100\right)/100}$$

$$f_{px} = 0.95$$

Although this factor may seem small, keep in mind that the area served is reduced in proportion to the square of the radius. The square of 0.95 is 0.90; thus the area served by stops along Barnes Road South is reduced by 10% from the ideal. This reduction is equivalent to one LOS grade if the area is transit-supportive.

The other pedestrian crossing factors are as follows:

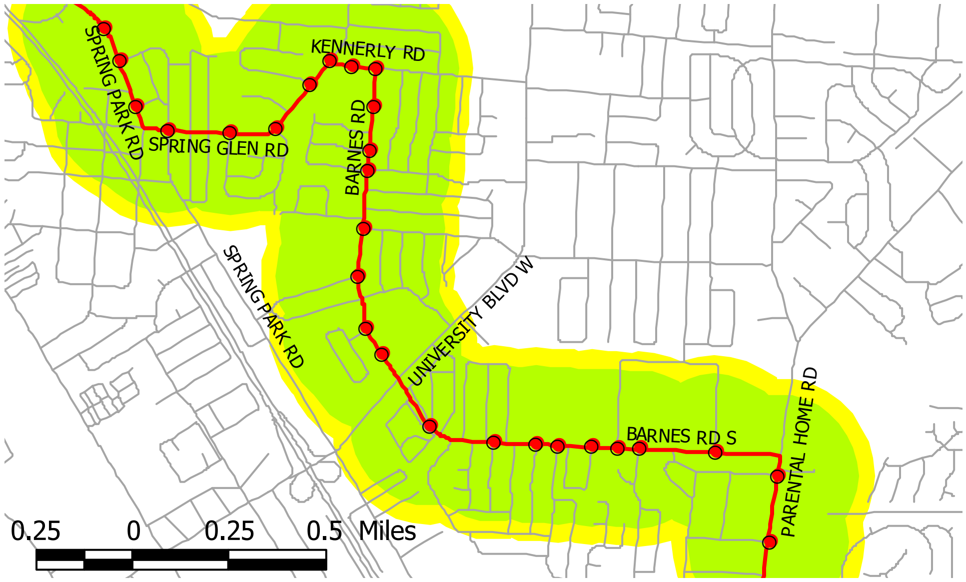
- Spring Park Road: 1.00
- Spring Glen Road (signalized intersection): 1.00
- Spring Glen Road (unsignalized intersections): 0.99
- Kennerly Road: 1.00
- Barnes Road North (signalized intersection): 0.96
- Barnes Road North (unsignalized intersections): 1.00
- Parental Home Road: 0.98

7. The last step is to calculate each stop's service radius, by multiplying 0.25 miles by the four factors. The results are as follows:

Street Name	Combined Factors	Adjusted Radius (mi)
Spring Park Road	0.85	0.213
Spring Glen Road-signalized	0.85	0.213
Spring Glen Road-unsignalized	0.84	0.210
Kennerly Road	0.85	0.213
Barnes Road North-signalized	0.82	0.205
Barnes Road North-unsignalized	0.85	0.213
Barnes Road South	0.81	0.203
Parental Home Road	0.83	0.208

8. In GIS, each stop can be buffered by the adjusted radius and the resulting service coverage area compared with the ideal area developed using a 0.25-mile radius. (No adjustment was made where the buffer crosses the freeway, as access underneath the elevated freeway is possible, as shown on the map.) The results are shown in Exhibit 3-57. The inner shaded area shows the adjusted service coverage area, while the outer shaded area shows the ideal area. Although visually the two areas do not seem that much different, in reality, the reduced area is 18% smaller than the ideal area. This difference is approximately equal to two LOS grades if the area is transit-supportive.

Exhibit 3-57
Reduced Service Coverage Area



The Results

The adjusted service coverage area is 18% smaller than the ideal service coverage area. Based on the relationships developed in Part 3 between average walking distances to transit and the number of people served, this result indicates that 18% fewer people are assumed to be served by this section of the route due to less-than-ideal street network patterns and street crossing delays.

In this example, the biggest impact on service coverage was due to the street pattern. Because this area is already developed, there is not much that can be done in the short term to improve pedestrian connectivity. (Longer term, zoning provisions to require more pedestrian connectivity as land redevelops could be considered.) However, lessons learned in this area could be applied in areas of Marbleton that have yet to be developed and that could be developed with better pedestrian connections.

In terms of pedestrian crossing difficulty, Barnes Road South and Parental Home Road are the most difficult to cross, with average delays of 60 to 100 seconds. From a delay standpoint, extra priority to pedestrian improvements could be considered here (other factors, such as safety—for example, due to high vehicle speeds or poor sight distances—should also be considered when prioritizing improvements).

Example Problem 7

The Situation

The operator of general public demand-responsive transit services in Livingston County wants to evaluate how well they provide service to their users. In particular, an agency goal is to ensure that every passenger with a time-sensitive appointment (e.g., a medical appointment or a school or work trip) is delivered to his or her destination no later than the scheduled time.

The Question

What is the agency's LOS for availability and for reliability in delivering passengers to their destination?

The Facts

Exhibit 3-58 shows a map of the county, while Exhibit 3-59 shows service and population statistics for its communities. Dial-a-ride service is available Monday through Friday in the county seat, Chillicothe. The southwestern portion of the county receives service once per week, while the northeastern portion of the county receives service twice per month. The van will deviate up to 5 miles from the route to pick up and drop off passengers on services from the outer parts of the county into Chillicothe.

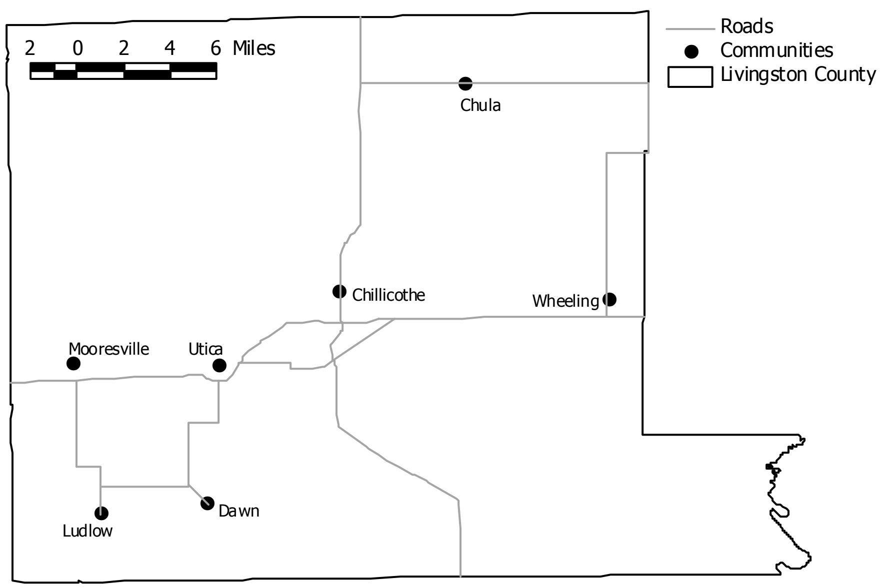


Exhibit 3-58
Livingston County

Exhibit 3-59
Livingston County Service Data

Location	Population	Days Served	Service Hours
Chillicothe	8,799	weekdays	6 am to 6 pm
Chula	183	first & third Thursdays	8 am to 5 pm
Dawn	25	Fridays	8 am to 5 pm
Ludlow	147	Fridays	8 am to 5 pm
Mooresville	100	Fridays	8 am to 5 pm
Utica	299	Fridays	8 am to 5 pm
Wheeling	284	first & third Thursdays	8 am to 5 pm
remainder of county	4,755	same as nearest community, if within 5 miles of the route	

Passengers outside Chillicothe must call no later than the day before to reserve a ride. At present, enough capacity is available to accommodate all passengers who request a ride a day in advance. Passengers within Chillicothe can call the same day for service, although the majority of trips are standing orders. A review of response times for requests for immediate service within Chillicothe found that nearly all could be served within 30 minutes.

Exhibit 3-60 compares scheduled and actual drop-off times for time-sensitive trips within Chillicothe on 2 days.

Exhibit 3-60
Arrival Time Data for Time-Sensitive Trips

Day 1		Day 2	
Scheduled	**Actual**	**Scheduled**	**Actual**
7:00 am	6:30 am	6:45 am	6:35 am
7:00 am	6:35 am	8:00 am	7:40 am
8:00 am	7:45 am	8:30 am	8:25 am
8:00 am	7:45 am	8:30 am	8:30 am
8:00 am	7:45 am	8:30 am	8:45 am
9:00 am	8:45 am	9:00 am	8:50 am
9:00 am	8:45 am	9:00 am	8:55 am
9:00 am	8:55 am	9:30 am	9:25 am
10:00 am	9:55 am	10:15 am	10:05 am
11:00 am	10:45 am	10:30 am	10:10 am
11:00 am	10:55 am	1:15 pm	1:15 pm
12:00 pm	11:35 am	1:30 pm	1:35 pm
1:00 pm	12:45 pm	1:45 pm	1:35 pm
3:00 pm	2:50 pm	2:00 pm	1:40 pm
3:00 pm	2:50 pm	2:15 pm	2:00 pm
4:00 pm	3:30 pm	2:30 pm	2:20 pm
		4:00 pm	3:50 pm

Outline of Solution

All of the information required to answer the questions has been provided. Response time LOS can be determined from the dispatcher's records of call-in times and the drivers' records of pick-up times. Service span LOS can be determined from the published schedule. On-time performance LOS can be determined from the drivers' records of scheduled and actual drop-off times.

Steps

1. Exhibit 3-32 will be used to determine response time LOS. Within Chillicothe, the average passenger requesting immediate service can be picked up within 30 minutes, which equates to LOS "1." For service from other communities, the agency policy is to reserve a ride no later than the day before. Since there is adequate capacity to meet all trip requests (i.e., no capacity constraints), the LOS for these areas is "4."
2. Exhibit 3-33 will be used to calculate service span LOS. Within Chillicothe, service is available 5 days per week, 12 hours per day, equivalent to LOS "3." The southwestern portion of the county receives service once per week, for 9 hours per day, equivalent to LOS "6." The northeastern portion of the county receives service twice per month, for 9 hours per day, equivalent to LOS "7." The remainder of the county has no service to Chillicothe and thus is at LOS "8." Exhibit 3-61 shows the results in the form of a map.

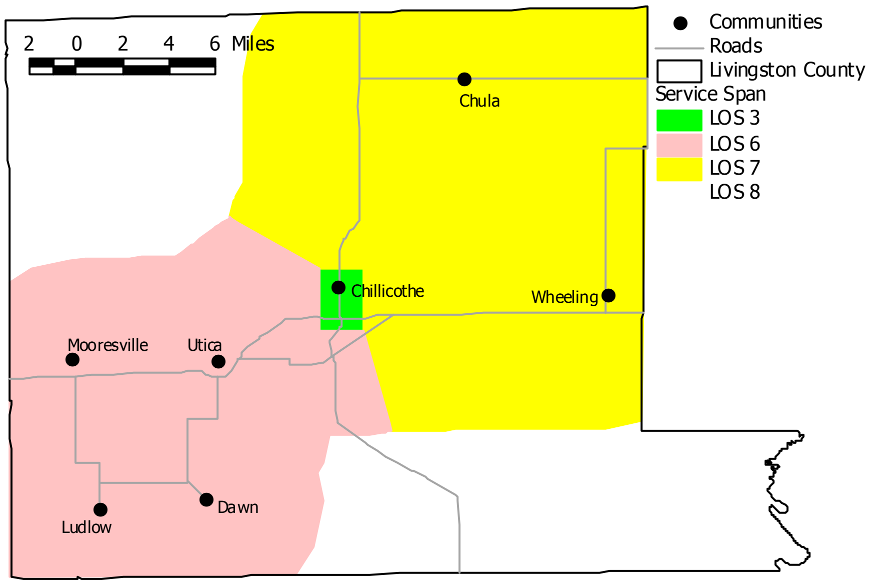


Exhibit 3-61
Service Span LOS Results

The results can also be expressed in terms of the number of people who receive service, as shown in Exhibit 3-62. The southwestern route serves about 30% of the county, while the northeastern route serves about 40% of the county. Assuming that the rural population is spread evenly about the county, the number of county residents living outside communities who receive service can be estimated.

Exhibit 3-62
Livingston County Service Data

LOS	Locations	Population	% of County Pop.
3	Chillicothe	8,799	60%
6	Dawn Ludlow Mooresville Utica rural SW county	1,998	14%
7	Chula Wheeling rural NE county	2,186	15%
8	rural NW & SE county	1,609	11%

3. Of the 33 time-sensitive trips studied, only twice did the passenger arrive after the scheduled time (Day 2, an 8:45 a.m. arrival for an 8:30 a.m. appointment, and a 1:35 p.m. arrival for a 1:30 p.m. appointment). The resulting on-time percentage is 93.9%, which is equivalent to LOS "3," from Exhibit 3-34.

The Results

Residents of Chillicothe have very good DRT service: service is available for one-half of the day on weekdays, and those riders who need immediate service are able to get it. About three-quarters of the county's residents outside Chillicothe have some service, with one-half of those people having access to at least weekly service. About one-quarter of the county's residents have no access to transit service.

The LOS "3" for on-time performance indicates that the agency is doing a relatively good job at getting its customers to their time-sensitive appointments on time.

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APPENDIX A: EXHIBITS IN METRIC UNITS

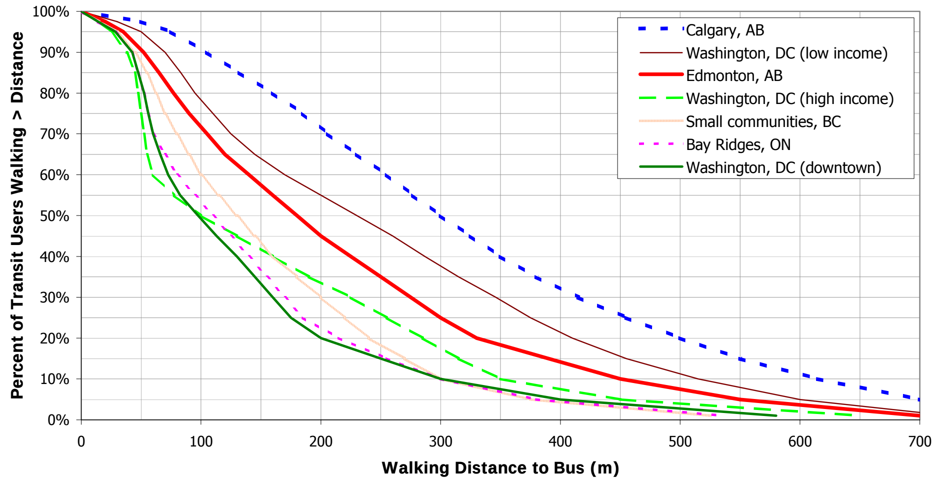

Exhibit 3-5m
Walking Distance to Bus Stops(R3,R20,R29,R36)

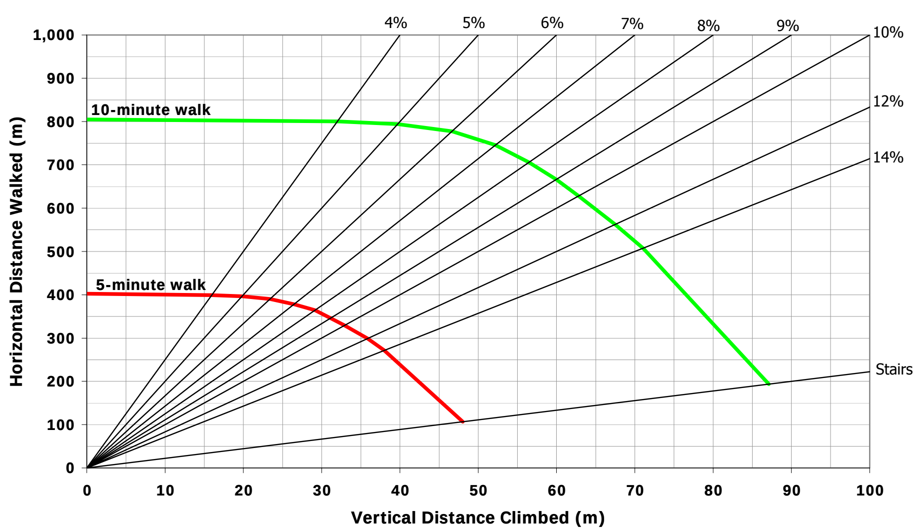

Exhibit 3-6m
Effect of Grade on Distance Walked(R23)

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