Bus Concepts

Bus Priority Treatments

Bus Preferential Treatments at Intersections

When buses operate in mixed traffic, the interference decreases bus speeds and lowers overall bus-vehicle and person capacity. The bus preferential treatments described in this section compensate by removing or reducing sources of delay, increasing bus speeds. When considering bus preferential treatments, the total change in person delay (both for passengers in buses and for motorists) should be taken into account. Bus priority treatments provide faster, more reliable bus operations, improving passenger quality of service.

Single Priority

Bus-signal priority measures at signalized intersections include passive systems, which are pretimed treatments adjusted manually to determine the best transit benefit while minimizing the effect on other vehicles, and active systems, which adjust the signal timing after sensing the arrival of a bus. Table (1) lists the most common bus-signal priority systems at intersections. Bus-signal priority measures can be passive (pretimed) or active (operated when a bus is detected).

Table (1): Bus Signal Priority System.

Treatment	Description
	Passive Priority
Adjust cycle length	Reduce cycle lengths at isolated intersections
Split phases	Apply multiple phases while maintaining original cycle length
Areawide timing plans	Preferential progression for buses through signal offsets
Bypass metered signals	Buses use special reserved lanes, special signal phases, or are rerouted to nonmetered signals
	Active Priority[a]
Phase extension	Increase phase time
Early start	Reduce other phase times
Special phase	Addition of a bus phase
Phase suppression	Skipped nonpriority phases
Preemption (unconditional)	Bus phase begins when all other intervals are satisfied
Preemption (conditional)	Same as above except certain conditions are used to determine when the bus phase should begin

Note:
a. Occurs after bus detection.
Source: Bullard and Nungesser (*10*).

Active priority should be implemented only at intersections operating at less than capacity, so that the changes to signal timing whenever a bus passes through the intersection do not worsen the intersection LOS. Automated systems that do not require bus driver intervention are preferable, since drivers might not always remember to activate the system. When coupled with two-way data communication and automatic vehicle location (AVL) equipment, on-bus signal priority systems can be set to activate signal priority only when a bus is behind schedule.

Queue Bypass

Queue bypasses allow buses to avoid queues of vehicles (such as those that develop at signalized intersections or freeway ramp meters) by providing a special lane. Queue bypass lanes can be shared with carpools and van pools.

Queue Jump

Queue jumps allow buses to move past long queues of vehicles at signalized intersections by using right-turn lanes or long off-line bus stops. Buses are exempted from any right-turn requirements at the intersection. Queue jumps allow buses to bypass long queues of vehicles at signalized intersections.

A special right-lane signal provides a green indication for a brief time before the green for the adjacent general traffic lanes. The bus then exits the right lane and merges into the lane to the left, ahead of the other traffic still stopped for the signal.
Alternatively, the bus can pull into the right-turn lane on a red signal and proceed to a farside off-line bus stop on green, avoiding the delay behind the queue in the regular lanes of the intersection.

Curb Extensions

Where streets have curbside parking and high traffic volumes, it may not be desirable for a bus to pull to the curb to stop, because it must then wait for a gap in traffic to pull back into the travel lane. In these situations, the curb can be extended into the parking lane so that buses can stop in the travel lane to pick up and discharge passengers. The additional area curbside can provide a clear area to load and unload wheelchair passengers in compliance with the ADA, to provide a bus shelter where otherwise there would not have been enough space, and to provide more room for passengers waiting for the bus. Curb extensions also can create more on-street parking, as the area before the bus stop, previously used for buses to pull to the curb, now can be used for additional parking. If there are bicycle lanes, they can be routed around the curb extension; but this can introduce potential bicycle- pedestrian conflicts. At intersections, curb extensions benefit pedestrians by reducing the width of street to cross.

Boarding Islands

Significant parking activity, stopped delivery vehicles, heavy right-turning traffic volumes, and other interferences often slow traffic in the right lane of a street with multiple lanes in the same direction. In these situations, buses might be able to travel faster in the lane to the left. Boarding islands allow bus stops between travel lanes; buses then can remain in a faster lane without merging to the right before every stop. However, pedestrian safety must be addressed in conjunction with boarding islands.

Person -Delay Considerations

In many cases, providing transit priority involves tradeoffs among the various users of a roadway. A bus queue jump at a traffic signal, for example, provides a time-saving benefit for bus passengers but causes additional delay for motorists, their passengers, bicyclists, and some pedestrians. Any consideration of transit priority measures should include the net change in person delay to all roadway users as a result of the priority treatment. Of course, other factors, such as cost, change in transit quality of service, and local policies encouraging transit use, also should be considered. Table (2) summarizes the advantages and disadvantages of the bus preferential treatments.

Table(2): Comparison of Bus Preferential Treatments.

Treatment	Advantages	Disadvantages
Signal Priority	• Reduces delay • *Improves reliability*	• Risks interrupting coordinated traffic signal *operation* • Risks lowering intersection LOS, if intersection is close to capacity • Requires ongoing interjurisdiction coordination • Buses on cross streets may incur added delay greater than the time saved by the favored route
Queue Bypass	• Reduces delay from queues at ramp meters or other locations	• Bus lane must be available and longer than the back of queue
Queue Jump	• *Reduces delay to queues at signals* • Buses can leapfrog stopped traffic	• *Right lane must be available and longer than* the back of queue • Right-turn or special transit signal required • Reduces green time available to other intersection traffic • Bus drivers must be alert for the short period of priority green time
Curb Extensions	• Reduces delay due to merging back into *traffic* • Increases riding comfort because buses don't need to pull in and out of stops • Increases on-street parking by eliminating need for taper associated with bus pullouts • Increases space for bus stop amenities • Reduces pedestrian street crossing *distances*	• Requires at least two travel lanes in bus *direction of travel to avoid blocking traffic while* passengers board and alight • Bicycle lanes require special consideration
Boarding Islands	• Increases bus speed by allowing buses to use faster-moving left lane	• Requires at least two travel lanes in bus direction of travel and a significant speed difference between the two lanes • Requires more right-of-way than other treatments • Pedestrian and ADA accessibility, comfort, and safety issues must be carefully considered
Parking Restrictions	• *Increases bus and auto speeds by* removing delays caused by automobile parking maneuvers	• *May significantly impact adjacent land uses* (both business and residential) • Requires ongoing enforcement
Bus-Stop Relocation	• Uses existing signal progression to bus' advantage	• May increase walking distance for passengers transferring to a cross-street bus
Turn Restriction Exemption	• Increases bus speed by eliminating need for detours to avoid turn restrictions	• Potentially lowers intersection LOS • Safety issues must be carefully considered
Exclusive Bus Lanes	• Increases bus speed by reducing sources *of delay* • Improves reliability • Increases transit visibility	• Traffic and parking effects of eliminating a *travel or parking lane must be carefully* considered • Requires ongoing enforcement

Source: Portland Office of Transportation (*11*).

Light-Rail Concept

Light-Rail and Streetcar Concept

Streetcars operate exclusively on city streets. Light-rail transit (LRT) started as a modification, separating streetcar operation from street traffic to allow higher speeds. LRT is characterized by versatility of operation; it can operate separated from other traffic below grade, at grade, on an elevated structure, or together with road vehicles on the surface.

LRT operations differ in station spacing and design, fare structure and collection methods, train length and propulsion, degree of access control, and markets served. Unlike streetcars, travel times between light-rail stations are relatively unaffected by increased passenger volumes or service.

General Capacity Ranges

The capacity of a rail line is determined by station (or stop) capacity or way capacity, whichever is smaller; in most cases, it is station capacity. Capacity depends on car size and station length, allowable standees, and the minimum spacing (or headway) between trains. This minimum headway is a function not only of dwell times at major stations, but also of train length, acceleration and deceleration rates, and train control systems. Figure (1) illustrates the main factors affecting rail vehicle capacity.

Time-space diagrams can be used to estimate the safe separation or minimum headway between trains. Sometimes theoretical approaches are used. A more common practice is to obtain the minimum spacing between trains based on actual experience, station dwell times, and signal control systems.

The passenger capacity of LRT depends on vehicle size, train length, and headway. However, the achievable LRT capacities also depend on design and policy considerations that reflect specific local constraints of station design, at-grade operations, and type of right-of-way.

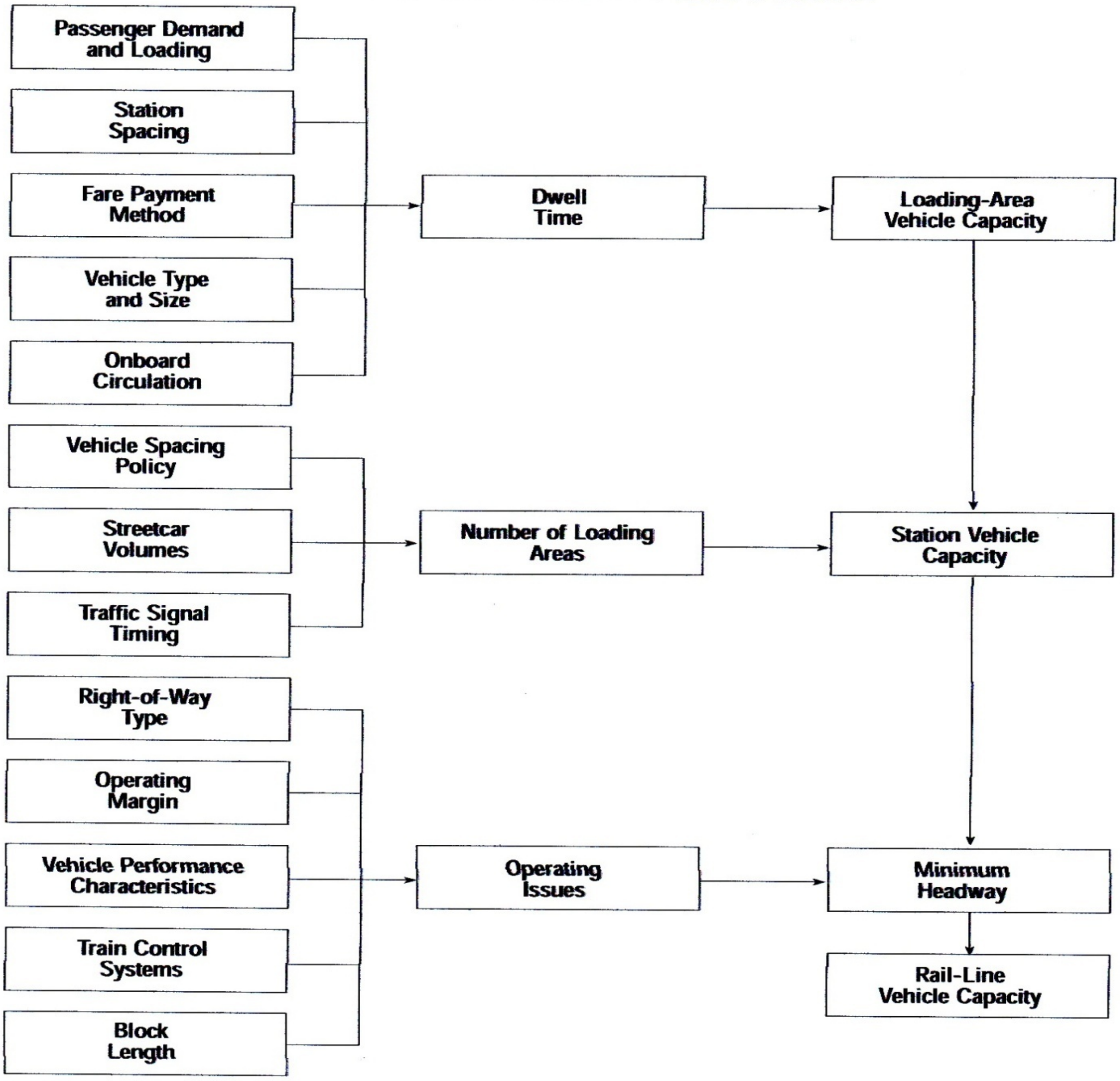
LRT trains usually are limited to a maximum of three cars for on-street operation. Longer trains usually cannot operate on city streets without simultaneously occupying more than the space between adjacent cross streets on short blocks, cannot clear at-grade intersections rapidly, and require long platform lengths at stations.

Minimum headways for light-rail systems depend on train length, platform and car design (high floor versus low floor), fare collection methods (prepayment versus pay on train), wheelchair accessibility, and headway controls (manual versus block signals). Manual operations can accommodate 80 to 100 single-unit cars per track per hour. When trains run under block signal controls, as is common with rapid-transit systems, 120-s headways are possible.

Current operating experience in the United States and Canada suggests maximum realizable capacities of 12,000 to 15,000 persons/track/h. However, European experience shows up to 20,000 persons/h. Typical ranges in person capacities are listed in Table (3).

One of the variables determining capacity is light-rail and streetcar travel time when operating in two directions using a single track. See Table (4) list values for travel time when local data not avalable.

Figure (1): Influences on Rail Vehicle Capacity.



Table(3): Typical Light - Rail Transit Person Capacity : 30 Trains/Track/h 28-30m Articulated Cars.

Cars/ Train	Passengers/Car				
	75[a]	100	125	150	175
1	2250	3000	3750	4500	5250
2	4500	6000	7500	9000	10,500
3	6750	9000	11,250	13,500	15,750
4	9000	12,000	15,000	18,000	21,000

Note:
a. All passengers seated.

Table (4): Default Values for Single -Track Light Rail and Streetcar Travel Time.

Term	Default Value
Jerk limiting time	0.5 s
Brake system reaction time	1.5 s
Dwell time	15–25 s
Service braking rate	1.3 m/s^2
Speed margin	1.1–1.2
Operating margin	10–30 s

Source: Parkinson and Fisher (*12*).

The value of the maximum single-track section speed should be the most appropriate speed limit for that section. A 60-km/h speed limit is a suitable value for most protected, grade-separated lines. If the single track section is on-street, then a speed at or below the vehicle speed limit should be used. If there are signalized intersections, an allowance of half the signal cycle should be added to the travel time for each such intersection, adjusted for any improvements possible from preemption.

<u>Rail- Priority Treatments</u>

Operating variability caused by traffic congestion has been reduced for the recently built on-street light-rail lines that operate in reserved lanes. Some older systems still operate extensively in mixed traffic and are subject to the variability in train throughput caused by a reduced effective green time for trains. Traffic queuing, left turns, and parallel parking can reduce LRT capacity.

Traffic signals can be a major impediment to LRT operation if they are not designed for the needs of LRT. Poor traffic signaling can make train operation slow, unreliable, and unattractive to potential passengers. These problems can be addressed through the use of signal priority or preemption and signal progression. Signal priority allows the light-rail train to extend a green phase or to speed the arrival of the next one. Depending on the frequency of intersections and traffic congestion, this can have a substantial impact on the flow of general traffic. As a result, LRT signal priority in congested areas is often limited in scope to avoid negative effects on other traffic.
Signal progression has supplanted priority or preemption for light-rail trains in many congested downtown areas. This technique gives trains a green window during which they can depart and travel to the next station on successive green signals. The benefits of

progression increase with greater station spacing as less accumulated time is spent waiting for the progression to start at each station. The progression frequently is part of the normal traffic-signal phasing and is fully integrated with signaling for automobiles on cross streets.

<u>Quality of Service Concept</u>

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

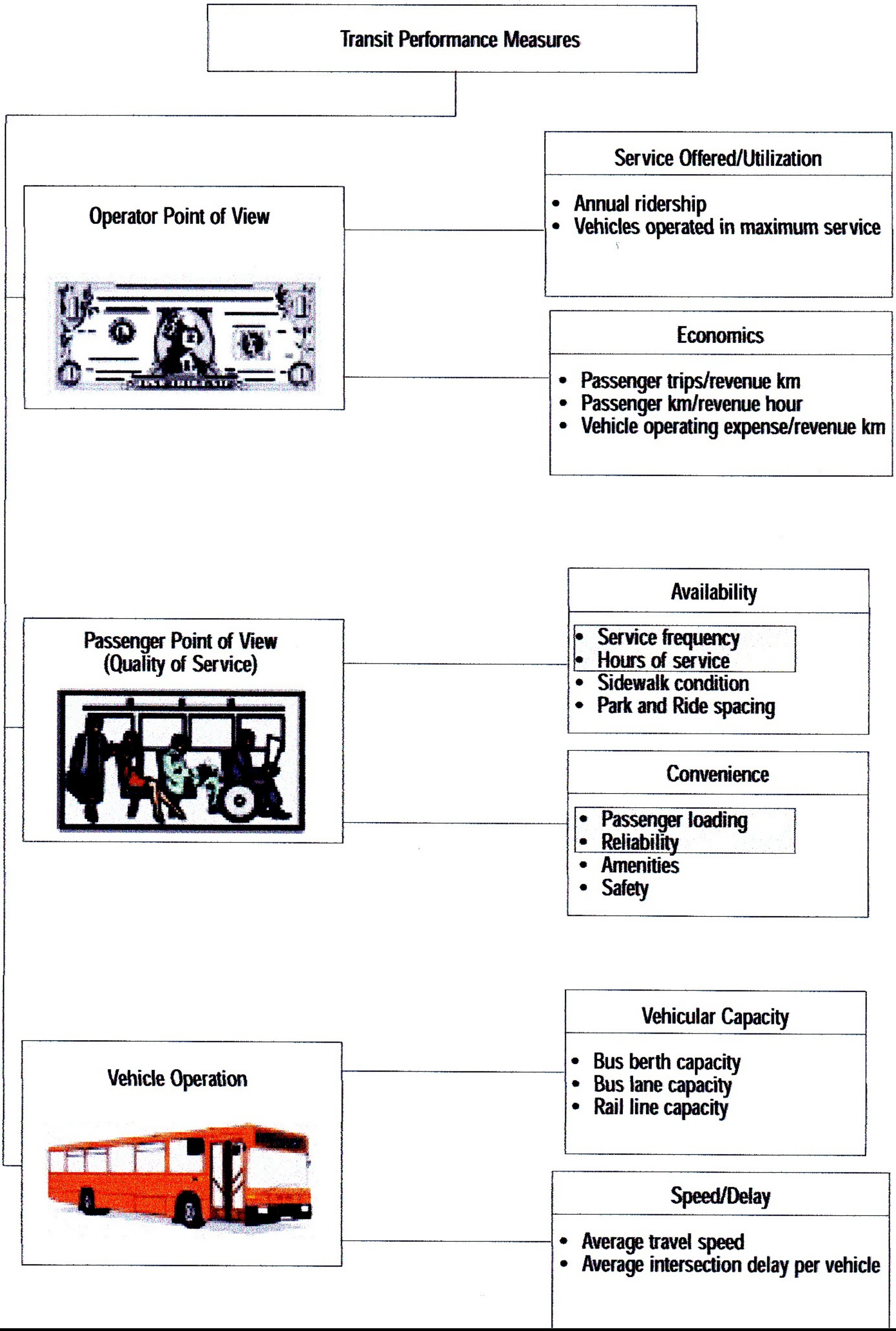
<u>Definitions</u>

• Transit performance measure; A quantitative or qualitative factor used to evaluate a particular aspect of transit service.

• Transit 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.

• LOS; Six designated ranges of values for a particular service measure, graded from A (best) to F (worst) based on a transit passenger's perception of a particular aspect of transit service.


Transit Performance Measures
Operator Point of View
Service Offered/Utilization
• Annual ridership
• Vehicles operated in maximum service
Economics
• Passenger trips/revenue km
• Passenger km/revenue hour
• Vehicle operating expense/revenue km
Passenger Point of View (Quality of Service)
Availability
• Service frequency
• Hours of service
• Sidewalk condition
• Park and Ride spacing
Convenience
• Passenger loading
• Reliability
• Amenities
• Safety
Vehicle Operation
Vehicular Capacity
• Bus berth capacity
• Bus lane capacity
• Rail line capacity
Speed/Delay
• Average travel speed
• Average intersection delay per vehicle

Quality -of - Service Factors

Service Coverage

Whether or not transit service is provided near a person's origin and destination is key in use of transit. Ideally, transit service is provided within a reasonable walking distance of the origin and destination, or demand-responsive service is available. The reasonableness of the walking distance varies from source to source and depends on the situation. For example, people will walk farther to rail stations than to bus routes and the elderly will not walk as far as younger adults. In general, 400 m or 5 min of walk time is the limit for a bus route’s typical service area; for a rail transit station.

If transit service is not provided near the origin, other options include driving to a park-and-ride lot or riding a bicycle to transit. Both of these options require that the transit operator provide additional facilities, such as parking lots, bicycle storage facilities.

Pedestrian Environment

Even if a transit stop is located within a reasonable walking distance of an origin and destination, the walking environment may not be amenable. Lack of sidewalks or poorly maintained sidewalks, lack of street lighting, and steep terrain all discourage pedestrian travel. Wide or busy streets without signalized crosswalks at regular intervals, or without pedestrian refuges in the median, also discourage pedestrian travel. A lack of pedestrian refuges poses difficulties, too, for transit operators providing service on urban streets.

Even if transit service is theoretically located within walking distance of both origin and destination, the areas around the transit stops must provide a comfortable walking environment for transit to be considered available.

Scheduling

How often and when transit service is provided are important factors in the decision to use transit. The more frequent the service, the shorter the wait when a bus or train is missed or when the exact schedule is not known, and the greater the flexibility customers will have in selecting travel times. The number of hours during the day when service is provided is also important._It does not matter whether a transit stop is located within walking distance if service is not provided at the desired time of travel; transit then cannot be an option.

Amenities

The facilities provided at transit stops and stations and on transit vehicles help make transit more comfortable and convenient. Typical amenities include the following :

• Benches, so that passengers can sit while waiting;
• Shelters to protect from wind, rain, snow, and sun;
• Informational signage, identifying the routes, their destinations, and scheduled arrivals;
• Trash receptacles for litter;

• Telephones, so that passengers can make personal calls while waiting or emergency calls when necessary;
• Vending facilities, 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; and
• Air conditioned vehicles, to provide a comfortable ride during hot and humid weather.

Transit Information

Potential riders need to know where and when transit service is available before they can begin using the service. Regular riders also should be informed about service changes that affect them. This information can be provided by a variety of means:

• Printed maps, schedules, and brochures. Passengers can pick these up on transit vehicles, at transit facilities, and at local businesses.
• Posted information on vehicles and at transit facilities. They can display schedule information onboard buses, at bus stops, and at bus terminals.
• Telephone. Information should be available by phone at the convenience of potential passengers (including weekends and evenings).
• Personal computers. Transit information can be posted on the Internet, and users can subscribe to e-mail lists that automatically send out service changes and other announcements.

Transfers

Requiring transfers between routes adds to a passenger's total trip time; this can be minimized with timed transfers. A missed transfer also can increase the length of a transit trip. Required transfers increase the complexity of a transit trip for a first-time passenger. Transfer surcharges also inhibit ridership.

Total Trip Time

Total trip time includes the travel time from the origin to a transit stop, waiting time for a transit vehicle, travel time onboard a vehicle, travel time from transit to the destination, and any time required for transfers between routes during the trip. In general,

both the absolute travel time and the travel time in relation to competing modes will factor in a traveler's decision about transit.
Total trip time is influenced by several factors, including the route spacing (affecting the walking distance to transit), the service frequency (affecting the waiting time), the frequency of stops, traffic congestion, signal timing, and the fare collection system.

Cost

Potential passengers weigh the cost and value of using transit against the out-of pocket costs and value of using other modes. Out-of-pocket transit costs consist of the fare for each trip or the cost of a monthly pass. Out-of-pocket automobile costs, in contrast, only include road and bridge tolls and parking charges, because other automobile costs—such as fuel, maintenance, insurance, taxes.

Safety and Security

Riders' perceptions—as well as the actual conditions—of the safety and security of transit enter into the mode-choice decision. Riders consider not only personal safety in relation to potential transit crime and vehicular crashes, Security can be improved by placing stops in well-lit areas with public telephones available for emergency calls. Transit systems use a variety of methods to enhance security on transit vehicles, including uniformed and plainclothes police officers.

Passenger Loads

Transit is less attractive when passengers must stand for long periods of time, especially in crowds. Crowded vehicles also slow down transit operation, adding time for passengers to get on and off. Most transit agencies assess passenger crowding based on the occupancy relative to the number of seats, expressed as a load factor. A factor of 1.0 means that all 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 commuting and high-speed, mixed-traffic operations. Inner-city service may approach a load factor of 2.0 or more, but other services will be between 1.0 and 2.0.

Appearance and Comfort

Some transit systems have established specific standards for transit facility appearance and cleanliness. Passengers are interested in ride comfort, which includes seat comfort, temperature control.

Reliability

Reliability affects the amount of time passengers must wait at a transit stop, as well as the consistency of a passenger's arrival time at a destination from day to day. Reliability encompasses on-time performance as well as the regularity of headways between successive transit vehicles. Uneven headways result in uneven passenger loadings, so that a transit vehicle arriving late picks up not only its regular passengers but others who have arrived early for the following vehicle. Reliability is influenced by traffic conditions (in on-street, mixed-traffic operations), staff availability and vehicle maintenance.

Framework

Transit quality-of-service measures are divided into two main categories:

availability, and comfort and convenience. According to the measures addressing spatial and temporal availability, if transit is located too far away or if it does not run at the times it is

needed, a potential user would not consider the transit service available, and therefore the quality of service would be poor. However, if transit service is available, the quality measures to evaluate user perceptions of comfort and convenience can be applied.
The different elements of a transit system require different performance measures:

• Transit stops. Measures should address transit availability and convenience at a single location. The performance measures in this category will vary from one location to another, since they depend on passenger volumes, scheduling, routing, and stop and station design.

• Route segments. Measures should address availability and convenience along a portion of a route, which can range from two stops to the entire length. These measures will tend to stay the same for the length of a route segment, regardless of conditions at an individual stop.

• Systems. Measures should describe availability and convenience for more than one route in a specified area (e.g., a district, city, or metropolitan area) or for a specified type of service (e.g., fixed route vs. demand responsive). System measures also can address door-to-door travel.

Combining the two performance measure categories with the three transit system elements produces the matrix shown in Table (5).

Table(5): Transit Quality -of - Service Freamework.

Category	Service & Performance Measures		
	Transit Stop	Route Segment	System
Availability	• Frequency[a] • Accessibility • Passenger loads	• Hours of service[a] • Accessibility	• Service coverage • % person-minutes served
Comfort and Convenience	• Passenger loads[a] • Amenities • Reliability	• Reliability[a] • Travel speed • Transit/auto travel time	• Transit/auto travel time • Travel time • Safety

Note:

Availabitiy

Transit Stops

The spatial aspect of transit availability at a transit stop is a given. During a typical hour-long analysis period, the hours of service are also a given. Therefore, frequency is the service measure for this category.

Route Segments

Of the three primary measures of transit availability as shown in Table (5); frequency, hours of service, and service coverage; frequency is used for transit stops, and service coverage is a given, since the route exists. Therefore, hours of service become the service measure for route segments. This is appropriate, since more than one route, each operating with different frequencies and travel times, can serve the same origins and destinations. In these cases, the focus is on the total span of time during which a given pair of origins and destinations can be accessed.

System

System availability measures relate to how many people have access to transit and how often. Service coverage within a transit area that has a population or job density to support at least hourly bus service (equivalent to a service frequency LOS E) is chosen as the service measure.

Comfort and Convenince

Transit Stops

Whether or not one can find a seat on a transit vehicle is an important measure of measure transit comfort. Passenger loads, the selected service measure, also influence boarding and alighting times, which in turn affect total dwell time and the capacity of transit routes.

Route Segment

Reliability is used as the service measure for route segments because it not only an aspect of service quality important to users, whether or not they get to their destination on time, but also affects other service measures. If transit vehicles arrive in a bunch, or not at all, the effective service frequency is reduced. Vehicles arriving late also have higher passenger loadings, since they pick up not only their regular passengers but others who have arrived early for the next vehicle.

System

The travel time difference between transit and automobile (the absolute difference in travel time from origin to destination by automobile and by transit) is an important consideration in a passenger's decision to use transit. System wide, this measure can be calculated by sampling locations and trip purposes within the analysis area, or by using a transportation planning model that can calculate trip times for all combinations of origins and destinations by transit and by automobile, for a variety of trip purposes.

An alternative performance measure is travel time, useful for indicating when higher speed service (such as limited-stop or express service) should be considered between two locations. Since travel time varies with the size of a community and the amount of traffic congestion (for transit modes operating in mixed traffic), travel time is not suitable as a service measure without defining different categories of city sizes. Safety, in terms of both accident and crime rates, affects the image of the entire transit system and is another system wide comfort and convenience measure.