**Mixed -Traffic Bus Facilities**

Mixed-traffic bus capacity is calculated in a similar manner as that for exclusive urban street bus lanes, except that the interference of other traffic sharing a lane with buses must be accounted for.

**Bus Lane Types**

Type 1 mixed-traffic lanes have one traffic lane in the direction the bus operates, shared by buses and other vehicles. Type 2 mixed-traffic lanes have two or more traffic lanes in the direction the bus operates. Traffic can use any lane, but buses typically operate in the curb lane. There are no Type 3 mixed-traffic bus lanes. Figure (1) depicts Type 1 and Type 2 mixed-traffic bus lanes.

****

**Type 1 Type 2**

**Figure(1): Mixed - Traffic Bus Lane Types.**

**Vehicle and Person Capacity**

The volume of mixed traffic sharing the curb lane with buses affects bus vehicle capacity in two ways: (a) the interference caused by other traffic in the lane, particularly at intersections, may block buses from reaching a stop or may delay a bus blocked behind a queue of automobiles, and (b) for off-line stops, the additional reentry delay encountered when buses leave a stop and reenter traffic may affect capacity. The latter source of delay is incorporated into the clearance time used to calculate bus stop capacity.

The former is accounted for by the mixed-traffic adjustment factor, , calculated using Equation (1):

........................... (1)

where:

= mixed-traffic adjustment factor,

= bus stop location factor,

*v* = curb-lane volume at critical bus stop, and

*c* = curb-lane capacity at critical bus stop.

Equation (2) is used to calculate the bus vehicle capacity of a mixed-traffic lane in which buses operate.

...........................(2)

where:

B= mixed-traffic bus lane capacity (buses/h),

= maximum number of buses at critical bus stop (buses/h),

= number of effective loading areas at critical bus stop, and

= mixed-traffic adjustment factor at critical bus stop.

The person capacity of buses operating in mixed traffic at the lane’s maximum load point may be calculated by multiplying the product of vehicle capacity and the maximum passenger load allowed by policy by a peak-hour factor.

**Speed**

The best way to determine bus travel speeds is to measure them directly. If this is not possible (for example, in planning future service), speeds can be estimated by driving the route or by using Equation (8), in lecture 15; to estimate bus speeds. The bus-bus interference adjustment factor, , should be set to 1.0 in mixed-traffic situations because the additional running time losses obtained from Table (5) in lecture 15; already account for the interference of other traffic sharing the lane with buses.

**Sizing Station Areas**

Given a desired LOS for the waiting area, based on the amount of space provided per passenger, and estimates of maximum boarding passenger volumes per vehicle per route at the stop, Equation (3) can be used to estimate the required size of the passenger waiting area, A.

......................... (3)

where:

A= passenger waiting area size (m2),

*, …,* = boarding passenger volume per transit vehicle for each route served by waiting area during peak 15 min (p), and

= design pedestrian area occupancy (m2/p).

**Light Rail and Streetcar Facilities**

Of the many varieties of rail transit—streetcars, light rail, rail rapid transit, commuter rail, and automated guideway—only streetcars and light rail can operate on urban streets. Streetcars often operate in mixed traffic and have characteristics similar to those of buses under these circumstances. Modern light rail systems running on street usually operate in reserved lanes and have significantly different characteristics from buses.

This lecture presents methods and procedures for estimating the vehicle and person capacity of streetcars and light rail vehicles operating on street.Determining on-street rail transit capacity is a three-step process:

1. determining the dwell time at the stop with the highest passenger volumes,

2. determining the track section providing the minimum headway,

3. and calculating capacity based on the minimum headway.

**Dwell Time**

The dwell time, td, is the time required to serve passengers at the busiest door divided by the number of available doors, or channels (most light rail doors are dual stream, having two channels) plus the time required to open and close the doors (typically 5 s for modern light rail vehicles, 10 s if folding or sliding steps are involved) . Time spent waiting at a station with the doors closed is incorporated into the operating margin. Equation (4) is used to calculate dwell time.

...............................(4)

where:

= dwell time (s),

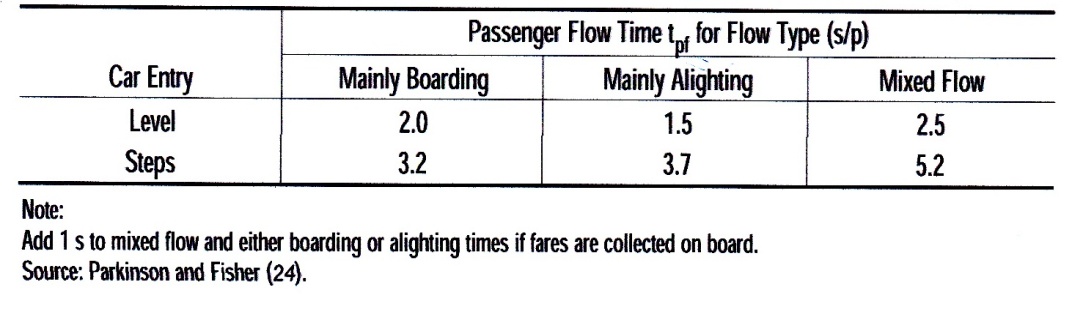
= number of channels per door for moving passengers,

= door opening and closing time (s),

= alighting passengers per rail through busiest door (p), and

= passenger flow time (s/p), from Table(1).

**Table(1): Rail Transit Passenger Flow Times (Single Stream).**

****

**Peak Passenger Volumes**

Some regional transportation models produce a.m. or p.m. peak flows for a 2-h period. In this case, either the model’s peak-hour conversion factor or a typical value of 60 percent is used to arrive at a peak-hour passenger volume. Next, the station with the highest passenger volume, either into or out of the station, is selected and the flow is classified as mainly boarding (70 percent or more of the passengers boarding), mainly alighting (70 percent or more of the passengers alighting), or mixed (all other situations). If the maximum load point station is downtown, it is likely that the flow will be primarily alighting in the morning and primarily boarding in the afternoon. If the station is also an interchange with another rail transit line, flows could be mixed.

Unless station flows are also available for the afternoon peak period, this process controlling headway assumes that the morning peak period defines the controlling headway and thus maximum capacity. Morning peaks tend to be sharper, whereas afternoon peaks are more dispersed as some passengers pursue other activities between work and the trip home. The hourly passenger flows are adjusted for peak 15-min passenger flows.

**Number of Doors Available**

The number of doors available, D, is given by Equation (5) and is related to the number of trains scheduled per hour, the average number of cars per train, and the number of doors per car. The number of cars per train is limited by the station length (typically one city block in CBD areas).

.............................. (5)

where:

D= number of doors available in peak hour,

= number of doors per car,

= number of cars per train, and

= scheduled headway (s).

**Passenger Flow at Controlling Door**

Except on heavily loaded rail lines operating close to capacity (a situation in which this method is not appropriate), passengers do not tend to spread evenly along a station platform, and uneven doorway utilization results. A value of 1.5 is recommended for light rail for the ratio of busiest door usage to average door usage. Equation (6) calculates passenger volume at the busiest door.

.............................. (6)

where:

= passenger volume through busiest door during peak 15 min (p), and

= ratio of busiest door usage to average door usage.

**Operating Margins**

An operating margin is the extra time added to a transit line’s headway to allow for irregular operation and ensure that one train does not delay the following train. It is suggested that a range be considered for the operating margin. When capacity is not an issue, 25 s or more is recommended. If necessary to provide sufficient service to meet the estimated demand, the operating margin can be reduced to 20 or even 15 s.

**Adjustment for Wheelchair Accessibility**

The accessibility of light rail transit to wheelchairs and other mobility devices (considered together with wheelchairs in this section) is a major issue for such systems. Boarding and alighting times with nonlevel loading of wheelchairs tend to be highly variable, depending on the skill of the passenger. There are five primary ways to provide wheelchair accessibility: car-mounted lifts, platform-mounted lifts, mini-high platforms, high platforms, and low-floor cars. To adjust for wheelchair accessibility, doors blocked by wheelchair lifts should be deducted from the total when Equation (4) is used to calculate dwell time.

**Minimum Headways**

An important element in calculating on-street light rail and streetcar vehicle and passenger capacity is determining the minimum headway possible between trains on an off-street block-signaled section,. This calculation is complicated by the variety of rights-of-way that can be employed. Most light rail transit lines use a combination of right-of-way types, which can include on-street operation (often in reserved lanes) and private right-of-way with grade crossings. The line capacity is determined by the weakest link; this link could be a traffic signal with a long cycle length but is more commonly the minimum headway possible on an off-street block-signaled section.

The train headway used for calculating capacities is the largest of the three potential controlling headways: on-street, block-signaled, and single-track headways. Equation (7) defines this relationship.

................................ (7)

where:

= minimum train headway (s),

= minimum on-street section train headway (s),

= minimum block-signaled section train headway (s), and

= minimum single-track section train headway (s).

**On-Street Operation**

It is difficult to encompass all the variables that affect on-street light rail and streetcar operation in a single formula. However, the capacity of on-street light rail may be greater in certain circumstances than on grade-separated, signalized rights-of-way, where higher speeds force the separation between trains to be increased.

The minimum headway between trains operating on street, , can be determined from Equation (8). For typical streetcar operations, where more than one streetcar can be present in a city block, or for light rail operations where the dwell time at the critical stop is long in comparison with the cycle length, dwell times and the effective green time control the minimum headway.

The closest possible headway for multiple-car light rail trains in on-street operation is often taken to be twice the longest traffic signal cycle.

........................... (8)

where:

= minimum on-street section train headway (s),

*g* = effective green time, reflecting reductive effects of on-street parking and pedestrian movements (mixed-traffic operation only) as well as any impacts of traffic signal preemption (s),

*C* = cycle length at stop with highest dwell time (s),

= maximum cycle length in line’s on-street section (s),

= dwell time at critical stop (s),

= clearance time between successive trains, defined as sum of minimum clear spacing between trains (typically 15 to 20 s or signal cycle time) and time for cars of a train to clear a station (typically 5 s per car) (s);

= one-tail normal variety corresponding to probability that queues of trains will form, from Table (3) in lecture 14; and

= coefficient of variation of dwell times (typically 40 percent for light rail operation in an exclusive lane and 60 percent for streetcar operation in mixed traffic).

**Block Signing**

Many light rail lines operate predominantly in private right-of-way with grade crossings or grade separations. These lines can take the form of routes that do not follow existing streets or that run in the medians of roads.

Trains are physically separated from other traffic except at crossings, operate with full signal preemption of cross-street traffic, and run at higher speeds than in on-street sections.

**Single Track Section**

Single-track sections used for two-way operation (as opposed to single tracks operating in one-way couplets) can constrain light rail and streetcar capacity.

Equation (9) computes the time to cover a single-track section, tst. This computation includes the time required to traverse the single-track section plus one train length at the maximum track section speed; time losses during acceleration, deceleration, and station stops; a speed margin to adjust for equipment not operating to performance specifications and train operators who do not push to the edge of the operating envelope (i.e., do not operate at the maximum permitted speed); and an operating margin to allow for off-schedule trains.

.................. (9)

where

= time to cover single-track section (s);

= length of single-track section (m);

*L* = train length (m);

= number of stations on single-track section;

= station dwell time (s);

= maximum speed reached (m/s);

= deceleration rate (m/s2) also used as a surrogate for twice average acceleration from 0 to ; Jerk-limiting time is an allowance for equipment features that taper the braking rate at the beginning and end of brake application to provide a smooth stop

= jerk-limiting time (s);

= operator and braking system reaction time (s);

*SM* = speed margin (constant); and

= operating margin time (s).

The minimum headway on a single-track section is twice the time required for a train to cover the single-track section and is given by Equation (10).

.......................... (10)

where:

= minimum single-track section train headway (s).

**Light Rail and Streetcar Capacity**

**Vehicle Capacity**

The maximum capacity of a light rail or streetcar line, in terms of the number of trains, T, is determined from the minimum headway by Equation (11):

............................. (11)

where:

T: maximum number of trains per hour.

**Person Capacity**

The maximum person capacity, P, of light rail and streetcar lines is the number of trains multiplied by their length, the number of passengers per meter of length set by policy, and a peak-hour factor. Alternatively, maximum person capacity can be determined by Equations (12) and (13) using the number of trains multiplied by the number of cars per train, the maximum allowed passenger load per car, and a peak-hour factor.

........................ (12)

where:

*P* = maximum single-track capacity in passengers per peak-hour direction (p),

*L* = train length (m),

= loading level (p/m), and

*PHF* = peak-hour factor.

........................... (13)

where:

= number of cars per train, and

= maximum allowed passenger load per car (p).

**Speed**

Light rail and streetcar travel time is influenced by the following factors:

• Running time required to travel the analysis section if no stops are made. For off-street

sections, the maximum operating speed should be used. For on-street streetcar operations (where streetcars share a lane with other traffic),“Urban Streets,” should be used. For on-street rail operations in an exclusive lane, either the posted speed for the street or the speed dictated by signal progression should be used, whichever is lower. If rail vehicles do not benefit from either traffic signal progression or traffic signal priority, traffic signal delays should be accounted for when running times are calculated.

• Dwell time at stops.

• Acceleration and deceleration time at stops for boarding and alighting passengers.

For the purposes of planning future transit service, travel time can be estimated by the procedures defined in Equations (14) through (17). Running time, , is related to distance traveled and the average free-flow speed (FFS) for the section being analyzed. FFS is taken to be the posted speed limit for on street operations and the maximum section operating speed for off-street operations. When these values vary over the transit route section being analyzed, a weighted average FFS can be calculated by multiplying the FFS for each section by the length of that section, summing these values, and dividing the result by the total length. A speed margin is used to adjust the running time to account for variations in transit equipment and the fact that drivers may not drive consistently at the FFS.

..................................... (14)

where:

= running time (s);

*SM* = speed margin, assumed to be 1.1;

*L* = analysis section length (km); and

= free-flow speed of train (km/h).

The acceleration and deceleration time, , is given by Equation (15):

............................. (15)

where:

= deceleration rate (m/s2) also used as a surrogate for twice the average acceleration from 0 to vf;

= jerk-limiting time (s); and

= operator and braking system reaction time (s).

Total travel time, , is computed by Equation (16):

........................ (16)

where:

= total travel times (s), and

*N* = number of stops or stations in analysis section.

Finally, average travel speed, , is computed by Equation (17):

............................................. (17)