2. **General Guidelines Common To All Transit Facilities**

This chapter addresses guidance that applies equally to bus facilities on highways, streets or off-line, including planning processes, capacity calculations, and design controls and criteria. Information that is more specifically pertinent to highway, street or off-line operating environments is found in chapters 3, 4 and 5 respectively.

A single bus route or bus rider will often use a combination of highway, street and off-line facilities to get from an origin to a destination. Effective transit facilities planning processes consider the customer and service needs along an entire journey. Concerted dialogue is often needed between those most familiar with transit service and customer needs and others who are experts in facility design and operation to ensure that facilities will meet transit objectives and well as the needs of other facility users. A variety of planning methods that apply to any bus transit facility are introduced here, including planning methods for an entire corridor or region.

Basics of bus capacity calculations are also included in Chapter 2, supplemented as appropriate in subsequent chapters. Bus stops are found in freeway, street and off-line environments, and capacity calculations related to bus stops are included here. Finally, this chapter includes information about the design driver and vehicle, design speeds, and roadway alignment geometry.

### 2.1. Functional Planning

There are many types of planning processes that can define, assess and recommend facility improvements to benefit bus transit service. Ideally, the process begins at the regional scale, where high level analyses are used to determine where more localized solutions are required, which are then defined more precisely in corridor or sub-area studies and then in facility-specific analyses. But just as often, good solutions will arise from localized studies and are incorporated into regional plans as a result. Most important is that local solutions and regional policies and priorities are in synch, and that improvements made regionally will work well together.

This section provides an overview and examples of planning processes used to identify, define and evaluate potential transit facility improvements. Guidance on specific planning methodologies is beyond the scope of this document.

#### 2.1.1. REGIONAL-SCALE TRANSIT/HOV FACILITIES PLANNING

Planning for bus transit facilities at the regional level may be part of the long-range transportation planning process conducted by an MPO, a special effort focusing on the development of a comprehensive HOV system, a system-level transit planning process, or other region-wide study. In any case, the planning process normally involves representatives from the MPO, the state department of transportation, the transit authority, local communities, the state police, and other groups.
In a general case, the regional planning process aims to consolidate regional and local highway, street and transit plans to make sure that the combination of projects selected best meets regional priorities. Regional-scale analyses can also be used to examine a portion of the regional transportation system, for example, transit services, park and ride lot needs, HOV or bus lane network priorities, or others subsystems that fall logically together. In most cases regional-scale studies tend to focus on ensuring that the collective result of all proposed projects will result in a continuous network of highways, streets or HOV lanes, an overall improvement in transit service times, coverage or frequency, and/or the best overall ratio of benefits to costs.

Examples of regional bus/HOV planning studies and the development of regional long-range transportation plans that include significant bus transit facility components are highlighted in this section. The use of sketch planning techniques and other approaches often used at the regional level are discussed in later sections.

**Examples of Regional HOV/Transit Plans**

As exemplified by the following case studies, regional transit facility investments are often associated with the planning of a system of bus/HOV lanes. The best mix of treatments is a localized decision making process involving an understanding of the transit markets being served. Note that with some exceptions, regional studies tend to focus more on higher capacity freeway facilities rather than on arterial street facility needs.

- **Dallas Freeway HOV System Plan.** The Dallas Bus/HOV System Plan for the year 2015 was jointly developed by the Texas Department of Transportation (TxDOT), Dallas Area Rapid Transit (DART), and the North Central Texas Council of Government (NCTCOG). The Texas Transportation Institute (TTI) conducted the technical analysis supporting the planning process. The system plan was developed to provide a link between the long-range planning activities and the detailed corridor alternatives analyses.

  The regional planning process focused on peak-hour passenger travel demand in the year 2015. The methodology used incorporated the costs associated with travel delay, construction, and operation while accounting for changes in travel behavior based on the travel time savings and the travel time reliability offered by HOV facilities. The desired outcome was to identify the lowest cost alternative in the various corridors for a given volume of person trips.

  An iterative process was used to examine multiple alternatives in each major freeway corridor. Right-of-way costs, transit operating costs, congestion costs, and other factors were identified for each alternative. The alternatives were evaluated to determine the bus/HOV system which best balanced cost and traffic flow, while considering transit system needs. The regional plan emerging from this process includes a mix of freeway bus/HOV lanes that work in association with a balance of transit investments made in the basic service, commuter and light rail. In some instances, multiple investments in express bus on HOV lanes and light rail are made in the same corridors, but each generally serves different markets.

- **Puget Sound (Seattle) High-Occupancy Vehicle Pre-Design Studies.** An extensive system of HOV lanes, park-and-ride lots, transit services, and supporting facilities has been implemented in the greater Seattle area. The Puget Sound HOV Pre-Design study was undertaken to help define the remaining parts of a comprehensive bus/HOV system in the area and to assist in identifying the priority elements of this network. The Washington State Department of Transportation (WSDOT) sponsored the study in cooperation with the Puget Sound Regional Council (PSRC), King County Metro, FHWA, and
other local agencies and jurisdictions. Eleven separate concurrent studies were conducted, examining safety and enforcement, direct access and freeway-to-freeway connection needs and future HOV lane expansion priorities. Although the evaluation criteria varied slightly for the different studies, the major evaluation measures included travel time savings, travel time reliability, person throughput, modal shifts, transit system connectivity, accessibility, impact on the general-purpose lanes, safety, cost, cost-effectiveness, enforcement, environmental impacts, social and land use factors, and phasing.

The results of the various studies were used to reevaluate the existing core HOV lane system plan and other supporting components. Additions, deletions, and modifications were made in the plan. Many elements of the study were funded as part of Sound Transit's phase 1 high capacity transit ballot initiative.

**Toronto Regional HOV Plan.** The Municipality of Metropolitan Toronto has conducted a number of planning efforts focusing on the development of a regional bus/HOV lane system. A network of dedicated lanes was first proposed in 1990 as part of a congestion management strategy. This effort lead to a more detailed study examining the role bus/HOV lanes could play in helping to manage traffic in the region, developing bus/HOV facility planning and design guidelines, and identifying a potential regional system network. Objectives of the study included identifying approaches to increase person movement, improve transit operations, and enhance air quality and environmental considerations. A number of alternatives were developed and evaluated based on factors such as bus ridership, demand, connections to major developments, system connectivity, and air quality impacts. The results of the study indicated that a bus/HOV system for the Toronto area is both feasible and warranted. The study presents a 30-year regional plan for freeway and arterial HOV and transit facilities.

### 2.1.2. PLANNING HOV FACILITIES AT THE CORRIDOR LEVEL

Greater detail is needed in the planning process for transit facilities at the corridor level. At this stage, transit treatments may be one of a number of possible improvements being considered or alternative strategies under investigation. These alternatives may involve different route or guideway alignments, including those on an existing freeway, arterial, or in a new right-of-way. Different transit service strategies may also be tested. Representatives from all appropriate agencies, local governments, and neighborhood and business organizations should be involved in a corridor level planning process. The following case studies highlight a few examples of corridor level transit/HOV studies.

**Examples of Corridor Level HOV/Transit Plans**

- **I-394 Corridor, Minneapolis.** Planning for the upgrading of US Highway 12 to become an interstate highway corridor on the west side of Minneapolis began in the 1960s. The roadway facility, which was a signalized four lane divided roadway, was added to the Federal Aid Interstate System as I-394 in 1968. An initial planning study for the corridor conducted by the Minnesota Department of Transportation (Mn/DOT) was started in 1970. A total of eight alternatives were evaluated, with four recommended for further study. Three of the four alternatives that were dropped involved all or partially new alignments, and all four required significant right-of-way acquisition. The four alternatives recommended for further study involved variations of the existing US 12 alignment. One of these was a no-build option, while the other three would have required additional right-of-way to widen the existing facility.
In response to concerns from neighborhood businesses and local groups related to the impact of these alternatives on adjacent land uses, transit alternatives were added to the study. The transit alternatives included an exclusive transit facility off of the US 12 alignment, an exclusive transit facility on the US 12 alignment, and a bus/HOV facility on the US 12 alignment with various priority bus treatments.

A consensus among the various agencies, as well as the public, did not emerge from the planning process on a preferred highway and transit alternative. In response to continued opposition by neighborhood groups in the corridor, the Minnesota Legislature passed a bill in 1975 requiring additional study of the corridor and limiting the final facility to not more than six general purpose traffic lanes.

As a result of this legislation, Mn/DOT and other agencies reexamined various alternatives. These alternatives considered including no-build, a metered freeway, a freeway plus light rail in the median, a freeway plus light rail on a separate alignment, a freeway with bus/HOV lanes in the median, and a freeway plus two light rail lines on different alignments. Based on additional analysis that examined projected population, employment, and travel growth, the recommended alternative included a mix of bus/HOV lanes supported by enhanced express bus transit services, rideshare programs, and parking management strategies. Transit facilities implemented included off-line transfer stations, park-and-ride lots, and a major HOV parking garage and multi-modal bus transfer station at the project terminus downtown.

I-279 Corridor, Pittsburgh. The Pittsburgh Interstate Network included a new freeway alignment on the north side of the city connecting with the Pennsylvania Turnpike. Planning in the corridor was initiated by the Pennsylvania DOT (formerly Bureau of Public Roads) in 1957. Two general alignments were considered, with the alternative that followed a new right-of-way to the northwest emerging as the preferred route. Both draft and final environmental impact statements were prepared on the project. The design included a six lane freeway, with provisions for median bus/HOV lanes, a fixed guideway line, or two additional general-purpose lanes in the median. Additional consideration was given to the bus/HOV facility component in the late 1970s. As a result, the final design for the freeway included a two lane, reversible barrier separated bus/HOV facility located in the freeway median with direct bus access from two outlying routes and direct access to downtown streets serving to distribute bus demand.

2.1.3. FACILITY-BASED PLANNING

Planning at the facility level requires the greatest amount of detail. In general, facility-based planning is only initiated once a decision has been made to move forward with a selected alternative or project. For example, if the recommended alternative from a corridor study is a bus or HOV lane, the facility-based planning process would examine the transit-specific elements associated with implementation.

Planning at the facility level may focus on more specific facility attributes, such as access treatments, park-and-ride lot locations, transit station needs and locations, and examination of incident management needs associated with location of bus services and park-and-ride lots, and other issues. A more detailed level of analysis is usually needed at this stage. Examples of specific facility-based studies are highlighted next.
Example of Facility-based HOV/Transit Projects

- I-45 North Freeway, Houston. The I-45 North Freeway bus/HOV project evolved over time. Planning for a contra-flow bus/vanpool lane on I-45 North started in the mid-1970s through the cooperative efforts of the Texas Highway Department, now the Texas Department of Transportation, and the City of Houston, now the Metropolitan Transit Authority of Harris County (METRO). A contra-flow lane was considered by the agencies as a possible short-term approach to addressing significant levels of traffic congestion during the peak hours by offering a transit alternative. Based on the results of an initial study, a contra-flow HOV lane demonstration project was implemented in 1975 and was very successful. More patrons became transit users than originally planned, so a number of newly inaugurated transit routes were augmented by hastily constructed park-and-ride lots and contract service providers. As a result of this success, planning soon began on a replacement transit facility. This planning process examined forecasted travel demand, origin and destination information, travel patterns, and other related data. This information was used to identify the most appropriate type of bus/HOV lane, access locations and treatments, transit services, and park-and-ride facilities. The recommendation from the planning process was to implement a one-lane reversible, barrier-separated transitway facility, with direct access points to park-and-ride lots at strategic locations. The contra-flow HOV lane was discontinued in 1984 with the opening of the first phase of the new barrier separated bus/HOV lane.

2.1.4. SKETCH PLANNING TECHNIQUES

Sketch planning represents a general or broad level of analysis. Sketch planning is most frequently used at a regional level or as a preliminary screen at the corridor and facility level. Sketch planning is intended to be a relatively simple process to help identify candidate areas, corridors, or facilities in need of transit facility improvements, those where transit facilities appear to be warranted, and the most logical type of treatment. Sketch planning may be a precursor to the more detailed evaluation described previously, or it may be a subpart of this process. The techniques outlined in this section are also appropriate for use within the context of other more detailed planning efforts.

The basic elements of the sketch planning process are described below:

- Identify Criteria. A variety of criteria may be used at the sketch planning level. These criteria, which should be identified and agreed upon early in the planning process, may include one or two or a series of factors. The criteria for evaluation should reflect established goals and objectives. Criteria commonly used in the sketch-planning process are:
  - Congestion Levels. Existing and forecasted traffic congestion levels in a corridor or on a facility provide a good indication of the need for some type of improvement, including a dedicated bus transit facility. For example, the presence of severe and recurring congestion (level of service (LOS) D or E and recurring average speeds of 30 mph or less) in the peak hours represents justification for a transit improvement.
  - Travel Patterns. The affected commute trips should be amenable for transit, either represented by express bus or conventional bus services. Trip ends to employment centers need to be concentrated enough that transit can provide a meaningful alternative in travel time. Trip lengths need to be long enough to generate the potential for time savings.
- **Current Bus Volumes.** Existing transit services, carpools, and vanpools in a corridor can be used to provide an indication of the potential use of a bus/HOV facility. A corridor with high levels of current ridership usually represents a better candidate than a corridor with low levels.

- **Travel Time Savings.** Estimating the potential travel time savings offered by the bus/HOV facility is important in generating potential mode splits to transit. Transfers in modes can adversely affect travel time savings gained along a dedicated lane, and these service characteristics need to be taken into account. An overall travel time savings of eight minutes is desirable to affect mode shifts to transit.

- **Projected Demand and Cost Effectiveness.** The number of buses and bus patrons needs to be significant enough to offset the capital and operating cost involved in the service provided.

- **Physical Characteristics.** The physical characteristics of a corridor or roadway may influence the ability to add a dedicated bus/HOV lane or to make any type of transit service improvement. Ensuring that a facility or other improvement can be accommodated is usually an important screening element.

- **System Continuity.** The success of transit facility may be further enhanced if it is part of a larger system. Consideration may be given during the screening process to those physical or service elements that are critical parts of an overall network plan.

- **System Staging and Scheduling.** An initial project must provide meaningful benefits. Staging considers a project can be implemented without adversely affecting other corridor users while generating meaningful, incremental benefits.

- **Environmental Issues.** Examining potential environmental benefits as well as possible negative impacts of a transit is needed to assessing the possible benefits and impacts at a preliminary.

- **Other Modes.** Other fixed guideway transit systems in operation or planned for the corridor or area should be considered. If other modes exist, the trip characteristics of the various transit and rideshare markets should be examined to ensure that the alternatives are compatible rather than competitive.

- **Collect Needed Data.** Various data needed for a determination of need and demand includes corridor traffic data, transit operations, rideshare use, and census data. Aerial photographs, land use maps and other physical resources are needed to ascertain many of the aspects identified above for key screening criteria.

- **Screening Process.** The screening process may be kept relatively simple, or a weighted evaluation process or other technique may be used that evaluates each alternative against some or many of the example criteria provided above. For screening, the criteria are either met or not met. A more complex approach may involve weighting the criteria. This technique places more value on locally determined key criteria. Another technique that may be used is a fatal flaw analysis. This approach identifies a few key criteria, called fatal flaws, which will eliminate an alternative from further consideration. A first-level screening may be conducted based on these elements in order to weed out projects without adequate potential to warrant further consideration.
Recommended Plan. A sketch planning process gives a quick indication of which potential projects deserve more detailed development and analysis. The results of the sketch planning process may be a preliminary regional, corridor or facility project plan, but further analysis is generally required to become the recommended design concept.

2.1.5. TRANSIT DEMAND ESTIMATION TECHNIQUES

A variety of transit demand models are used, depending on the scale of the proposed improvement(s), on whether the improvement will have an effect on both transit ridership and traffic, and on the number of options under consideration among other factors. Demand modeling is a complex science, and specific guidance on methodologies for demand modeling is beyond the scope of this document; however the following discussion provides an introduction to the topic.

Regional-scale traffic and transit models are generally used and maintained by the Metropolitan Planning Organization (MPO); transit and local agencies often maintain models that are customized to focus in on decisions facing the agency, but that are consistent with regional population and employment forecasts and overall travel demand that have been developed and often adopted by the MPO. Customized models may include more detail for a geographic area, or focus only on changes to transit service levels and/or coverage while holding traffic conditions constant.

In general, large scale travel demand models, including transit demand models, are most accurate for examining flows of people or vehicles across a screenline over a group of transit routes; most are less accurate at predicting volumes on an individual bus route. These models are best used to show the different performance and impacts resulting for alternative proposals (including the proposal to take no action), assuming that all other aspects of the transportation and land use system are held constant.

In the full-scale regional modeling process, current and future land use (households and jobs, primarily) are estimated first, since land use activities determine the number of trips that will be generated or attracted in an analysis zone. Then most regional transportation models will usually include the following four steps:

- **Trip generation**, which determines the number of trips likely to be produced by households or attracted by businesses (for example) based on the land use, demographics and other factors determined to be significant in each region;

- **Trip distribution**, which determines where the trips “attractions” and “productions” generated during trip generation will be connected, based on the “impedance,” or travel time between zones (which can change as a result of a large-scale project);

- **Modal split** (or “mode choice”), which determines the proportion of trips between any two analysis zones that will be carried on different modes, based on the relative travel times and costs for travel on each mode between each zone pair as well as demographic and other factors, and finally;

- **Trip assignment**, where the trips forecasted between zones for each mode are assigned to specific streets or transit routes. Speeds are then recalculated and trips are re-assigned, and the assignment process iterates until an equilibrium is reached in the system where little change results from further speed recalculation.

The four-step modeling process is an iterative process, since changes made at any step can have an effect on the outcome of another step. Large-scale changes in
transportation access can also impact the original assumptions about land use
distribution that was the basis for the model run.

For sketch planning purposes, or for smaller scale analyses, transit demand changes
that would result from a change in transit service can be estimated using elasticities
for incremental travel time or costs, based on locally observed behavior. Models that
use this approach are sometimes referred to as “incremental” models or even as
“pivot point” analysis. Travel times should be calculated to include all components of
a transit trip, including time to walk or drive to transit, wait time (which depends on
the service headway), in-vehicle time and time waiting to transfer between transit
services. These different components of travel time may be weighted differently to
reflect the fact that passengers experience some components of travel time to be
more “costly” than others.

2.1.6. GENERAL DESIGN AND COST FACTORS

The capital and operating costs associated with various types of HOV facilities will
vary greatly depending upon local conditions. Local factors influencing cost include
the availability of right-of-way and the purchase price of needed land; contracting
procedures; soil, wetlands, and other environmental issues; weather factors
influencing the construction season; and special considerations such as the need for
seismic considerations in Southern California. While generalized unit costs may be
helpful for sketch planning purposes, for large-scale projects, a site-specific cost
estimate is needed based on a specific design concept under consideration.

2.1.7. COST EFFECTIVENESS ANALYSIS

Cost effectiveness is usually determined by comparing the capital costs associated
with a project with the anticipated benefits, although life-cycle costs may also be used
in order to factor in operating and maintenance costs. The benefits may include
quantifying the total travel time savings, operational and fleet savings realized by
public transit operators, or other project-specific objectives. Cost-effectiveness
analysis data often accompany cost information in order to provide a simple and
intuitive indicator of the relative effectiveness per dollar invested on a project.

2.2. Bus Transit Capacity

2.2.1. INTRODUCTION

Transit capacity is different than highway capacity in that it deals with the movement
of both people and vehicles; it depends on the size of the transit vehicles and how
often they operate; and it reflects the interaction between passenger traffic
concentrations and vehicle flow. Transit capacity depends on the operating policy of
the transit agency, which normally specifies service frequencies and allowable
passenger loadings.

This section provides an introduction to bus capacity concepts, and basic capacity
calculations. For bus service planning, capacity considerations are often coupled
with quality of service measures. For more information on bus quality of service
concepts or measures, please see the TCRP Transit Capacity and Quality of Service
Manual [3].
Figure 2-1
Bus Vehicle Capacity Factors

Reference: [3]
Throughout this section, the distinction is made between person and vehicle capacity. Vehicle capacity reflects the number of buses that can be served by a loading area, bus stop, bus lane, or bus route during a specified period of time. Person capacity reflects the number of people that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard or restriction, and with reasonable certainty.

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

Transit capacity is commonly calculated for three locations:

- loading areas (bus berths);
- bus stops; and
- bus lanes.

Each of these locations has one or more elements that determine its capacity, and each of these elements has a number of factors that further influence capacity. Figure 2-1 illustrates the key factors that affect vehicle capacity. Factors that influence vehicle capacity at bus stops and loading areas are discussed in section 2.2.2. Factors that influence vehicle capacity in bus lanes are discussed separately in section 2.2.3. Person capacity is dealt with in section 2.2.4.

### 2.2.2. VEHICULAR CAPACITY OF BUS STOPS AND LOADING AREAS

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

The most common form of loading area is a linear bus stop along a street curb. In this case, loading areas can be provided in the travel lane (on-line), where following buses may not pass the stopped bus, or out of the travel lane (off-line), where following buses may pass stopped vehicles. Figure 2-2 depicts these two types of loading areas.

A loading area on a freeway or busway is normally designed as an off-line facility.

Reference: [3]
The main elements affecting loading area vehicle capacity are:

- **Dwell Time.** Dwell time is the single most important factor affecting vehicle capacity. It is the time required to serve passengers at the busiest door, plus the time required to open and close the doors.

- **Dwell Time Variability.** The variations in dwell time among different buses using the same loading area affect capacity. The greater the variation, the lower the vehicle capacity.

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

Each of these elements is addressed in more detail below.

**Dwell Time**

*Dwell Time Factors*

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

There are five main factors that influence dwell time. Two of these relate to passenger demand, while the other three relate to passenger service times:

- **Passenger Demand and Loading.** The number of people boarding and/or alighting through the highest-volume door is the key factor in how long it will take for all passengers to be served. If standees are present on-board a bus as it arrives at a stop, or if all seats become filled as passengers board, service times will be higher than normal because of congestion in the bus aisleway. The mix of alighting and boarding passengers at a stop also influences how long it takes all passenger movements to occur.

- **Bus Stop Spacing.** The fewer the stops, the greater the number of passengers who will need to board at a given stop. A balance is required between too few stops (which increase the distance riders must walk to access transit and increase the amount of time an individual bus occupies a stop) and too many stops (which reduce overall travel speeds due to the time lost in accelerating, decelerating, and possibly waiting for a traffic signal every time a stop is made).

- **Fare Payment Procedures.** The amount of time passengers must spend paying fares is a major factor in the total time required per boarding passenger. This time can be reduced by minimizing the number of bills and coins required to pay a fare; encouraging the use of pre-paid tickets, tokens, passes, or smart cards; using a proof-of-payment fare-collection system; or developing an enclosed, monitored paid-fare area at high-volume stops. In addition to eliminating the time required for each passenger to pay a fare on-board the bus, proof-of-payment fare collection systems also allow boarding passenger demand to be more
evenly distributed between doors, rather than being concentrated at the front door.

- **Vehicle Types.** Low-floor buses decrease passenger service time by eliminating the need to ascend and descend steps. This is particularly true when a route is frequently used by the elderly, persons with disabilities, or persons with strollers or bulky carry-on items.

- **On-Board Circulation.** Encouraging people to exit via the rear door(s) on buses with more than one door decreases passenger congestion at the front door and reduces passenger service times.

In certain locations, dwell time can also be affected by the time to board and disembark passengers in wheelchairs, and for bicyclists to load and unload bicycles onto a bus-mounted bicycle rack.

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

Three methods can be used to determine bus dwell times:

- **Method 1: Field Measurements.** The most accurate way to determine bus dwell times at a stop is to measure them directly. An average (mean) dwell time and its standard deviation can be determined from a series of observations.

- **Method 2: Default Values.** If field data or passenger counts are unavailable for a bus stop, the following representative values can be used to estimate dwell time: 60 seconds per CBD, transit center, major on-line transfer point, or major park-and-ride stop, 30 seconds per major outlying stop, and 15 seconds per typical outlying stop.

- **Method 3: Calculation.** This method requires that passenger counts or estimates be available, categorized by the number of boarding and alighting passengers. Calculation steps are described below.

### Dwell Time Calculations

- **Step 1: Obtain hourly passenger volume estimates.** These estimates are required only for the highest-volume stops. When skip-stop operations are used, estimates are needed for the highest-volume stops in each skip-stop sequence.

- **Step 2: Adjust hourly passenger volumes for peak passenger volumes.** Equation 2-1 shows the peak hour factor (PHF) calculation method. Typical peak-hour factors range from 0.60 to 0.95 for transit lines. A PHF close to 1.0 may well indicate system overload (underservicing) and reveal the potential for more service. If buses operate at less than 15-minute headways, the denominator of Equation 2-1 should be adjusted appropriately (e.g., 3P20 for 20-minute headways). Equation 2-2 adjusts hourly passenger volumes to reflect peak-within-the-peak conditions.
\[ PHF = \frac{P}{4P_{15}} \]

*Equation 2-1*

\[ P_{15} = \frac{P}{4(PHF)} \]

*Equation 2-2*

where:

- \( PHF \) = peak hour factor;
- \( P \) = passenger volume during the peak hour (p); and
- \( P_{15} \) = passenger volume during the peak 15 minutes (p).

❖ **Step 3:** Determine the base passenger boarding and alighting time. This time can be estimated using values given in Table 2-1 or by using the following values for typical operating conditions—single-door loading, pay on bus:

- **Boarding Time**
  - 2.0 seconds pre-payment (includes bus pass, free transfer, pay-on-leave)
  - 2.6 seconds single ticket/token
  - 3.0 seconds exact fare
  
  Add 0.5 seconds to the above boarding times if standees are present on the bus.

- **Alighting Time**
  - 1.7 to 2.0 seconds

The typical boarding and alighting times for bus passengers, as they affect the dwell time, are summarized in Table 2-1. The times tabulated in Table 2-1 reflect regular users with few enquiries to the bus driver. Wheelchair or bicycle loading or unloading would increase dwell time.

The boarding and alighting times translate to vehicular capacity figures for on-line linear bus stops; if the peak number of buses per hour using the stop is known, the size of the stop can be determined using Table 2-2 (assuming 15 sec clearance time, 25 % probability that a bus will have to wait for a loading area, and 60 % coefficient of variation of dwell times).

❖ **Step 4:** Adjust the passenger boarding and alighting times for special conditions. Multiply the base boarding and/or alighting times, as appropriate, by the following factors if the corresponding condition occurs:

- Heavy two-way flow through a single door: 1.2
- Double-stream door: 0.6
- Low-floor bus: 0.85
### Table 2-2

**Estimated Bus Capacity of On-Line Single Linear Bus Stop**

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<tr>
<th>Dwell Time (s)</th>
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</table>

*Reference: [3]*
Step 5: **Calculate the dwell time.** The dwell time is the time required to serve passengers at the busiest door, plus the time required to open and close the doors. A value of 2 to 5 seconds for door opening and closing is reasonable for normal operations. The number of boarding and alighting passengers per bus through the busiest door during the peak-within-the-peak (typically 15 minutes), $P_b$ and $P_a$, are determined by the proportions of boarding and alighting passengers per bus during the peak period.

$$t_d = P_a t_a + P_b t_b + t_{oc}$$

*Equation 2-3*

where:

- $t_d$ = dwell time (s);
- $P_a$ = alighting passengers per bus through the busiest door during the peak 15 minutes (p);
- $t_a$ = passenger alighting time (s/p);
- $P_b$ = boarding passengers per bus through the busiest door during the peak 15 minutes (p);
- $t_b$ = passenger boarding time (s/p); and
- $t_{oc}$ = door opening and closing time (s).

**Dwell Time Variability**

Not all buses stop for the same amount of time at a stop, depending on fluctuations in passenger demand between buses and between routes. Dwell time variability is influenced by the same factors that influence dwell time. Based on field observations of bus dwell times in several U.S. cities reported in TCRP Report 26 [4] the coefficient of variation of dwell times (the standard deviation of dwell times divided by the mean dwell time) typically ranges from 40% to 80%, with 60% recommended as an appropriate value in the absence of field data.

**Table 2-3**

Values of Percent Failure Associated with $Z_a$

<table>
<thead>
<tr>
<th>Failure Rate</th>
<th>$Z_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0%</td>
<td>2.330</td>
</tr>
<tr>
<td>2.5%</td>
<td>1.960</td>
</tr>
<tr>
<td>5.0%</td>
<td>1.645</td>
</tr>
<tr>
<td>7.5%</td>
<td>1.440</td>
</tr>
<tr>
<td>10.0%</td>
<td>1.280</td>
</tr>
<tr>
<td>15.0%</td>
<td>1.040</td>
</tr>
<tr>
<td>20.0%</td>
<td>0.840</td>
</tr>
<tr>
<td>25.0%</td>
<td>0.675</td>
</tr>
<tr>
<td>30.0%</td>
<td>0.525</td>
</tr>
<tr>
<td>50.0%</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Reference: [3]
The probability that a queue of buses will not form behind a bus stop, or failure rate, can be derived from basic statistics. The value $Z_a$ represents the area under one "tail" of the normal curve beyond the acceptable levels of probability of a queue forming at a bus stop. Typical values of $Z_a$ for various failure rates are shown in Table 2-3. A design failure rate should be chosen for use in calculating a loading area's capacity. Higher design failure rates increase bus stop capacity at the expense of schedule reliability. Capacity occurs under normal conditions at a 25% failure rate.

Suggested values of $Z_a$ are the following:

- **CBD stops.** $Z_a$ values of 1.440 down to 1.040 should be used. They result in probabilities of 7.5 to 15 percent, respectively, that queues will develop.

- **Outlying stops.** A $Z_a$ value of 1.960 should be provided wherever possible, especially when buses must pull into stops from the travel lane. This results in queues beyond bus stops only 2.5 percent of the time. $Z_a$ values down to 1.440 are acceptable, however.

**Impact of Wheelchair Accessibility on Dwell Time**

All new transit buses in the U.S. are equipped with wheelchair lifts or ramps. When a lift is in use, the door is blocked from use by other passengers. Typical wheelchair lift cycle times are 60 to 200 seconds, while the ramps used in low-floor buses reduce the cycle times to 30 to 60 seconds (including the time required to secure the wheelchair inside the bus). The higher cycle times relate to a small minority of inexperienced or severely disadvantaged users. When wheelchair users regularly use a bus stop, the wheelchair lift time should be added to the dwell time.

**Impact of Bicycles on Dwell Time**

Some transit systems provide folding bicycle racks on buses. When no bicycles are loaded, the racks typically fold upright against the front of the bus. (Some systems also use rear-mounted racks, and a very few allow bikes on-board on certain long-distance routes.) When bicycles are loaded, passengers deploy the bicycle rack and load their bicycles into one of the available loading positions (typically two are provided). The process takes approximately 20 to 30 seconds. When bicycle rack usage at a stop is frequent enough to warrant special treatment, a bus' dwell time is determined using the greater of the passenger boarding/alighting time or the bicycle loading/unloading time.

**Clearance Time**

Once a bus closes its doors and prepares to depart a stop, there is a period of time, known as the clearance time, during which the loading area is not available for use by the following bus. Part of this time is fixed, consisting of the time for a bus to start up and travel its own length, clearing the stop. For on-line stops, though, this is the only component of clearance time. For off-line stops, however, there is another component to clearance time: the time required for a suitable gap in traffic to allow the bus to re-enter the traffic stream and accelerate. This re-entry delay is variable and depends on the traffic volume in the travel lane adjacent to the stop and increases as traffic volumes increase. The delay also depends on the platooning effect from upstream traffic signals. Some states have passed laws requiring motorists to yield to buses re-entering a roadway; depending on how well motorists comply with these laws, the re-entry delay can be reduced or even eliminated. Many bus operators avoid using off-line stops on busy streets in order to avoid this re-entry delay.
Various studies have evaluated these factors, either singly or as a whole. Based on those studies, start-up and exiting time may be assumed to be 10 seconds. Re-entry delay can be measured in the field or, at locations where buses re-enter a traffic stream, may be estimated from Table 2-4, based on traffic volumes in the adjacent travel lane. If buses must wait for a queue from a signal to clear before they can re-enter the street, Table 2-4 should not be used; instead, re-entry delay should be estimated using the average queue length (in vehicles), the saturation flow rate, and the start-up lost time.

Some states in the U.S. have passed laws requiring other traffic to yield to transit vehicles that are signaling to exit a stop. In these locations, the re-entry delay can be reduced or even eliminated, depending on how well motorists comply with the law. Transit priority measures, such as queue jumps at signals, can also reduce or eliminate re-entry delay.

### Table 2-4

**Average Bus Re-Entry Delay into Adjacent Traffic Stream**  
*(Random Vehicle Arrivals)*

<table>
<thead>
<tr>
<th>Adjacent Lane Mixed Traffic Volume (veh)</th>
<th>Average Re-Entry Delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>300</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>500</td>
<td>4</td>
</tr>
<tr>
<td>600</td>
<td>5</td>
</tr>
<tr>
<td>700</td>
<td>7</td>
</tr>
<tr>
<td>800</td>
<td>9</td>
</tr>
<tr>
<td>900</td>
<td>11</td>
</tr>
<tr>
<td>1,000</td>
<td>14</td>
</tr>
</tbody>
</table>

*Reference: [3]*

**Overall Bus Capacity of Loading Areas**

The maximum number of buses per loading area per hour is:

\[
B_{bb} = \frac{3,600 (g / C)}{t_c + (g / C) t_d + Z_d c_v t_d}
\]

*Equation 2-4*

where:

- \(B_{bb}\) = maximum number of buses per loading area per hour;
- \(g / C\) = ratio of effective green time to total traffic signal cycle length (1.0 for a stop not at a signalized intersection);
- \(t_c\) = clearance time between successive buses (s);
$t_d$ = average (mean) dwell time (s);
$Z_a$ = one-tail normal variate corresponding to the probability that queues will not form behind the bus stop; and
$cv$ = coefficient of variation of dwell times.

Table 2-5 presents the estimated number of buses that can use a bus loading area for $g/C$ ratios of 0.5 and 1.0 (the ratio of green signal time to the total traffic signal cycle length). Values are tabulated for dwell times ranging from 15 to 120 seconds. Values for $g/C$ times between 0.5 and 1.0 can be interpolated; values for $g/C$ times less than 0.5 and for other dwell times can be computed directly from Equation 2-4. These maximum capacities assume adequate loading area and bus stop geometry. Other assumptions are 15-second clearance time, 25% queue probability, and 60% coefficient of variation of dwell times. Guidelines for the spacing, location, and geometric design of bus stops are given in TCRP Report 19 [2]. These guidelines must be carefully applied to assure both good traffic and transit operations.

**Table 2-5**

<table>
<thead>
<tr>
<th>Dwell Time (s)</th>
<th>$g/C = 0.5$</th>
<th>$g/C = 1.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>63</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>43</td>
<td>63</td>
</tr>
<tr>
<td>45</td>
<td>32</td>
<td>46</td>
</tr>
<tr>
<td>60</td>
<td>26</td>
<td>36</td>
</tr>
<tr>
<td>75</td>
<td>22</td>
<td>30</td>
</tr>
<tr>
<td>90</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>105</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>120</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

NOTE: Assumes 15-second clearance time, 25% queue probability, and 60% coefficient of variation in dwell times.

Reference: [3]

**Overall Capacity of Bus Stops**

A bus stop is an area where one or more buses load and unload passengers. It consists of one or more loading areas. Bus stop vehicle capacity is related to the vehicle capacity of the individual loading areas at the stop, the bus stop design, and the number of loading areas provided. Off-line bus stops provide greater vehicle capacity than on-line stops for a given number of loading areas, but in mixed-traffic situations, bus speeds may be reduced if heavy traffic volumes delay buses exiting a stop. The design of off-street bus terminals and transfer centers entails additional considerations, which are addressed in Chapter 5.
The vehicle capacity of a bus stop depends primarily on the following two elements:

- the vehicle capacity of the individual loading areas that comprise the bus stop
- the number of loading areas provided and their design.

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

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

- **Probability of Queue Formation.** The probability that queues of buses will form at a bus stop, known as the failure rate, is a design factor that should be considered when sizing a bus stop.

- **Loading Area Design.** Loading area designs other than linear (sawtooth, drive-through, etc.) are 100% effective: the bus stop vehicle capacity equals the number of loading areas times the vehicle capacity of each loading area, since buses are able to maneuver in and out of the loading areas independently of other buses. Linear loading areas, on the other hand, have a decreasing effectiveness as the number of loading areas increases, because it is not likely that the loading areas will be equally used. Buses may also be delayed in entering or leaving a linear loading area by buses stopped in adjacent loading areas.

- **Traffic Signal Timing.** The amount of green time provided to a street that buses operate on affects the maximum number of buses that could potentially arrive at a bus stop during an hour.

### Table 2-6

**Efficiency of Multiple Linear Loading Areas at Bus Stops (Buses/h)**

<table>
<thead>
<tr>
<th>Loading area #</th>
<th>Efficiency #</th>
<th># of Cumulative Effective Loading Areas</th>
<th>Efficiency %</th>
<th># of Cumulative Effective Loading Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1.00</td>
<td>100</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>85</td>
<td>1.85</td>
<td>85</td>
<td>1.85</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>2.45</td>
<td>75</td>
<td>2.60</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>2.65</td>
<td>65</td>
<td>3.25</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>2.70</td>
<td>50</td>
<td>3.75</td>
</tr>
</tbody>
</table>

*NOTE: On-line values assume that buses do not overtake each other*

Reference: [3]
Clearance time (the time from the closing of the bus doors to the re-entry of the bus into the traffic stream) is minimal for on-street stops but can be significant if the bus must re-enter a high-volume fast-moving traffic stream from a bus bay. Clearance delays can be minimized through careful siting of the bus stop, provision of a bus lane or HOV lane (to reduce the number of vehicles in the adjacent through lane), and laws or regulations requiring through traffic to yield to buses.

As shown in Table 2-6, increasing the number of loading areas at a linear bus stop has an ever-decreasing effect on capacity as the number of loading areas increases (doubling the number of loading areas at a linear bus stop does not double capacity). When more than three loading areas are required, sawtooth, pull-through, or other non-linear designs should be considered, but note that they offer less flexibility in operations and are not normally used in on-street operations.

The off-line loading area efficiency factors given in Table 2-6 are based on experience at the Port Authority of New York and New Jersey’s Midtown Bus Terminal. The on-line loading efficiency factors are based on simulation and European experience. The exhibit suggests that four or five on-line linear loading areas have the equivalent effectiveness of three loading areas. Note that to provide two “effective” on-line loading areas, three physical loading areas would need to be provided, since partial loading areas are never built. Once again, it should be noted that Table 2-6 applies only to linear loading areas. All other types of multiple loading areas are 100% efficient—the number of effective loading areas equals the number of physical loading areas.

The vehicle capacity of a bus stop in buses per hour is given by Equation 2-5:

\[
B_s = N_{eb}B_{bh} = N_{eb} \frac{3,600(g / C)}{t_c + (g / C)t_d + Z_a c c t_d}
\]

Equation 2-5

where:

\[
B_s = \text{maximum number of buses per bus stop per hour; and}
\]

\[
N_{eb} = \text{number of effective loading areas, from Table 2-6.}
\]

Table 2-7 provides estimated capacities of on-line bus stops. This exhibit shows the number of buses per hour for various numbers of loading areas, dwell times, and g/C ratios. It assumes 15-second clearance time, 25% queue probability, and 60% coefficient of variation of dwell times. The obtain the vehicle capacity of non-linear on-line bus stops, multiply the one-loading-area values by the number of loading areas provided. The maximum capacities attainable are 3.0 times those of a single loading area.

Figure 2-3 provides a further guide for estimating on-line linear bus stop capacity. It shows the number of buses per hour for selected dwell times and g/C ratios based on a 15-second clearance time. Increasing the number of linear loading areas has a much smaller effect on changes in capacity than reducing dwell times. Note that for dwell times greater than 60 seconds, the differences between a g/C of 0.5 and 1.0 are small.
Table 2-7
Estimated Maximum Capacity of On-Line Linear Bus (bus/h)

<table>
<thead>
<tr>
<th>Dwell Time (s)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/C 0.50</td>
<td>g/C 1.00</td>
<td>g/C 0.50</td>
<td>g/C 1.00</td>
<td>g/C 0.50</td>
</tr>
<tr>
<td>30</td>
<td>43</td>
<td>63</td>
<td>79</td>
<td>117</td>
<td>105</td>
</tr>
<tr>
<td>60</td>
<td>26</td>
<td>36</td>
<td>48</td>
<td>67</td>
<td>64</td>
</tr>
<tr>
<td>90</td>
<td>19</td>
<td>25</td>
<td>35</td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td>120</td>
<td>15</td>
<td>20</td>
<td>27</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

NOTE: Assumes 15-second clearance time, 25% queue probability, and 60% coefficient of variation of dwell times. To obtain the vehicle capacity of non-linear on-line bus stops, multiply the one-loading-area values by the number of loading areas provided.

Reference: [3]

Figure 2-3
Bus Stop Maximum Vehicle Capacity Related to Dwell Times and Number of Loading Areas

Reference: [3]
### 2.2.3 VEHICULAR CAPACITY OF BUS LANES

**Busways**

An exclusive busway is typically a dedicated two-way roadway offering bus-only operation in each direction. Exclusive busway vehicle and person capacity can be computed using appropriate assumptions regarding the nature of intersection crossings, type of bus used, maximum allowable bus loading, the distribution of ridership among stops, the peak hour factor, and the type of loading area. The most important factor in preserving capacity on a busway is allowing for separate loading lanes at stations which do not obstruct the main roadway.

If the busway extends into a central business district (CBD) (for example, the Seattle Bus Tunnel) and has limited number of stations in the downtown area, the busway’s passenger distribution characteristics will be similar to those of a fixed rail guideway. A reasonable design assumption is that 50 percent of the maximum load point volume is served at the heaviest CBD busway station—assuming a minimum of three stops in the downtown area. (For comparison, the Washington-State Street subway station in Chicago accounts for about half of all boarding passengers at the three CBD stops on the State Street subway line.)

<table>
<thead>
<tr>
<th>Stations: On-Line/Off-Line</th>
<th>Loading Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>On</td>
<td>Off</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Passengers boarding at heaviest station</strong></td>
<td></td>
</tr>
<tr>
<td>Boarding passengers per bus</td>
<td>20</td>
</tr>
<tr>
<td>Boarding time per passenger (s)</td>
<td>2.0</td>
</tr>
<tr>
<td>Dwell time (s)</td>
<td>40.0</td>
</tr>
<tr>
<td><strong>Vehicle Capacity</strong></td>
<td></td>
</tr>
<tr>
<td>Loading area capacity (bus/h)</td>
<td>42</td>
</tr>
<tr>
<td>Effective loading areas</td>
<td>2.45</td>
</tr>
<tr>
<td>Station capacity (bus/h)</td>
<td>103</td>
</tr>
<tr>
<td><strong>Passengers/hour—maximum load point</strong></td>
<td></td>
</tr>
<tr>
<td>Peak—flow rate (15 min x 4)</td>
<td>4,120</td>
</tr>
<tr>
<td>Average—peak hour (with PHF)</td>
<td>2,760</td>
</tr>
</tbody>
</table>

**Loading condition A:** Single-door conventional bus, simultaneous loading and unloading.

**Loading condition B:** Two-door conventional bus, both doors loading or double-stream doors simultaneously loading and unloading.

**Loading condition C:** Four-door conventional bus, all double-stream doors loading.

**Loading condition D:** Six-door articulated bus, all doors loading.

**NOTE:** Assumes 10-second clearance time, 7.5% failure rate, 60% coefficient of variation, 3 linear loading areas, g/C = 1.0, PHF = 0.87, 50% of passengers board at heaviest CBD station, 40 seats per conventional bus, 60 seats per articulated bus, no standees allowed.

Reference: [1]
Peak hour factors of 0.67 to 0.75 are reasonable for busways, depending on the location and type of operation.

Illustrative CBD busway vehicle and person capacities are given in Table 2-8 for a variety of bus types and service conditions. The key assumptions are:

- Fares are pre-paid at CBD busway stations. This allows all doors to be used for loading, which greatly decreases the service time per passenger, since several passengers can board at the same time.
- Fifty percent of the maximum load point passengers board at the heaviest stop. A peak hour factor of 0.67 is assumed.
- No delays due to signals (grade-separated busway for vehicles and pedestrians).
- The bus clearance time at stops is 10 seconds. The design failure rate is 7.5% and a 60% coefficient of variation is assumed.
- Three linear loading areas are provided at each station.
- The maximum load point passenger volume is limited to 40 passengers per bus for standard buses and 60 passengers per bus for articulated buses; this corresponds to a load factor of approximately 1.00 and provides a seat for all passengers.

Highway / Freeway Bus Lanes

Calculating Vehicle Capacity

Freeway bus/HOV lanes are designed to increase the potential person-moving capacity of a congested highway by reserving one or more lanes, either part-time or full-time, for the use of transit buses and vehicles with multiple occupants. When the regular freeway lanes experience congestion, vehicles in the HOV lane should still travel freely. As a result, transit is provided a time-savings benefit that encourages modal shifts to use transit services. In order to maintain the public perception that dedicated lanes are effectively used while still operating in free-flow, bus/ HOV lanes should operate with enough vehicles to achieve a perception of use, but not at or lane capacity. This level of service can be calculated using the procedures given in the Highway Capacity Manual (HCM [6]) chapters related to freeways.

Calculating the theoretical bus capacity, or service volume, for an exclusive bus lane is not practical because few transit agencies or locales schedules so many buses as to come close to the bus vehicle capacity of a basic freeway segment, and the number of buses that can actually be scheduled along a freeway may be constrained by the vehicle capacity of the on-line bus stops along the HOV lane section or by the bus stops located upstream or downstream of the bus lane. For example, the maximum number of buses using an exclusive bus lane in North America, 735 buses per hour, is achieved through an A.M. peak hour contraflow lane serving the Lincoln Tunnel in New York, with no stops along the lane, and with a 210-berth bus terminal to receive these buses on the downstream end.
Calculating Speed

The average speed of a bus operating on a busway or freeway HOV lane depends on three factors:

- the running speed of the bus in the lane;
- bus stop spacing; and
- dwell time at bus stops.

The Highway Capacity Manual may be used to estimate the running speed of a bus in a busway or freeway HOV lane, given the free-flow speed of the lane, the traffic volume in the lane, and the mix of passenger vehicles and buses using the lane. (Note that this estimated speed assumes that the lane is operating below capacity.)

The time required to travel through a given length of busway or HOV lane, without stopping, can be calculated from this running speed.

Bus stop spacing affects the number of times a bus must dwell, as well as the number of times the bus experiences added delay due to deceleration and acceleration into and out of stops. A rate of 1.2 m/s² (4.0 ft/s²) may be assumed for an acceleration and deceleration rate, in the absence of local data. Table 2-9 presents average travel speeds for a selection of running speeds, dwell times, and bus stop spacings. As expected, average bus speeds decrease as the stop spacing increases or as the average dwell time per stop increases.

Table 2-9

Estimated Average Speeds of Buses Operating in Freeway HOV Lanes

<table>
<thead>
<tr>
<th>Stop Spacing (km)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 km/h Running Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>53.4</td>
<td>46.6</td>
<td>41.2</td>
<td>37.0</td>
</tr>
<tr>
<td>2.5</td>
<td>61.6</td>
<td>55.9</td>
<td>51.1</td>
<td>47.1</td>
</tr>
<tr>
<td>3.0</td>
<td>64.1</td>
<td>58.9</td>
<td>54.4</td>
<td>50.6</td>
</tr>
<tr>
<td>4.0</td>
<td>67.4</td>
<td>63.0</td>
<td>59.1</td>
<td>55.7</td>
</tr>
<tr>
<td>5.0</td>
<td>69.6</td>
<td>65.8</td>
<td>62.4</td>
<td>59.3</td>
</tr>
<tr>
<td>90 km/h Running Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>56.4</td>
<td>48.7</td>
<td>42.9</td>
<td>38.4</td>
</tr>
<tr>
<td>2.5</td>
<td>66.3</td>
<td>59.7</td>
<td>54.3</td>
<td>49.8</td>
</tr>
<tr>
<td>3.0</td>
<td>69.3</td>
<td>63.2</td>
<td>58.1</td>
<td>53.8</td>
</tr>
<tr>
<td>4.0</td>
<td>73.5</td>
<td>68.3</td>
<td>63.8</td>
<td>59.8</td>
</tr>
<tr>
<td>5.0</td>
<td>76.3</td>
<td>71.8</td>
<td>67.7</td>
<td>64.1</td>
</tr>
<tr>
<td>100 km/h Running Speed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>58.6</td>
<td>50.4</td>
<td>44.2</td>
<td>39.4</td>
</tr>
<tr>
<td>2.5</td>
<td>70.3</td>
<td>62.8</td>
<td>56.9</td>
<td>52.0</td>
</tr>
<tr>
<td>3.0</td>
<td>73.9</td>
<td>67.0</td>
<td>61.3</td>
<td>56.5</td>
</tr>
<tr>
<td>4.0</td>
<td>79.1</td>
<td>73.0</td>
<td>67.9</td>
<td>63.4</td>
</tr>
<tr>
<td>5.0</td>
<td>82.5</td>
<td>77.2</td>
<td>72.5</td>
<td>68.4</td>
</tr>
</tbody>
</table>

NOTE: Assumes constant 1.2 m/s² acceleration/deceleration rate.

Reference: [3]
**Arterial Bus Lanes**

Bus operations on an arterial street are influenced by many factors. Ideally, buses operate with perfect predictability and consistency on a fixed schedule with no delay-causing interference. Bus travel time is a function of:

- time in motion;
- time spent at stops (dwell time);
- time spent at traffic signals;
- right-turn delays; and
- traffic congestion / interference delays.

The need and justification for the provision of transit facilities on a street will therefore stem from the ability of those facilities to address some or all of the factors that cause travel time delay (and hence unreliability and inconsistency).

**Speed for Buses in Motion**

The combination of passenger comfort criteria (governed by standees) and vehicle power / weight ratio produces bus acceleration and deceleration rates lower than smaller vehicles. A rate of 1.2 m/s² (4.0 ft/s²) may be assumed for a bus acceleration and deceleration rate, in the absence of local data.

Once in motion, buses are normally capable of operating at the posted speed limit on an arterial street.

**Delay to Buses at Traffic Signals**

The component of the bus trip that involves delays to buses at traffic signals may be calculated using the procedures of the HCM 2000 [6].

**Impact of Right Turns on Bus Speed**

Right turn vehicles can affect bus operations in a through lane in three ways:

- Turning vehicle deceleration or acceleration in front of a bus;
- Delays due to additional queuing at traffic signals; and
- Delays due to conflicting pedestrian movements.

Figure 2-4 illustrates the relationship between bus lane capacity and right-turning volume.

Conflicting pedestrian volumes under 200 / h have little effect on bus vehicle capacity, but have substantial effects at higher conflicting volumes, especially as right-turning volumes increase. However, when there are no right-turn conflicts, pedestrian volumes have no impact on vehicle capacity, and the lines for a given dwell time converge to a single point. It can also be seen that the lines for a given pedestrian volume converge toward a point at which the right-turn capacity is exceeded and the bus-lane vehicle capacity drops to zero. Between these two extremes, bus vehicle capacity steadily declines as right-turning volumes increase.
The impact of right turns can be overcome to some extent by the bus operating pattern; a two-stop skip-stop operation, for example, produces a bus-lane vehicle capacity in the order of 67% higher than conventional all-stops operation.

**Impact of Traffic Congestion on Buses**

Bus vehicle capacity while traveling in a mixed traffic lane will decline in proportion to the use of that lane by other vehicles. The degree to which bus flow will be affected is also a function of the operating pattern (all-stop, skip-stop, or platooned), the ability for buses to bypass stopped vehicles (including other buses), bus stop form and spacing, and traffic signal operations.

Figure 2-5 illustrates the operational capacity of a curb lane with varying combinations of buses and other vehicles.

### 2.2.4 PERSON CAPACITY OF BUS FACILITIES

Person capacity is commonly calculated for three locations:

- bus stops;
- bus routes, at the maximum load point; and
- bus lanes, at the maximum load point.
Figure 2-5
Mixed-Traffic-Lane Bus Vehicle Capacity

As Figure 2-6 shows (on the following page), in addition to the factors discussed in the previous section relating to vehicle capacity, there are other factors that must be considered when calculating person capacity.

Operator Policy

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

Passenger Demand Characteristics

How passenger demand is distributed spatially along a route and how it is distributed over time during the analysis period affects the number of boarding passengers that can be carried. The spatial aspect of passenger demand, in particular, is why passenger capacity must be stated for a given location, not for a route or a street as a whole.
During the period of an hour, passenger demand will fluctuate. The peak hour factor reflects passenger demand volumes over (typically) a 15-minute period during the hour. A bus system should be designed to provide sufficient capacity to accommodate this peak passenger demand. However, since this peak demand is not sustained over the entire hour and since not every bus will experience the same peak loadings, actual person capacity during the hour will be less than that calculated using peak-within-the-peak demand volumes.

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

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

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

The relationship between the vehicle capacity of bus facilities and the elements of person capacity described above is illustrated in Figure 2-7.

**Figure 2-7**

Person Capacity Calculation Process

Reference: [3]

**Person Capacity of a Bus Stop**

The person capacity of a bus stop is related to the number of people boarding and alighting at the bus stop, which influences the vehicle capacity of the bus stop. Equation 2-6 shows this relationship:

\[ P_s = B_s P_{15} \]

**Equation 2-6**

where:

- \( P_s \) = person capacity of a bus stop (p/h);
- \( B_s \) = vehicle capacity of the bus stop (buses/h), from Equation 2-5;

and

\[ P_{15} \] = peak 15-minute passenger interchange per bus (p/bus).

**Person Capacity of Bus Routes and Bus Lanes**

The person moving capacity of a busway, bus route or bus lane at its maximum load point under prevailing conditions is determined by multiplying the allowed passenger loading set by operator policy by the number of each type of bus operated during the analysis period (typically one hour) times a peak hour factor:

\[ P_{milp} = P_{max} f_{milp} (PHF) \]

**Equation 2-7**
where:

\[ P_{mlp} = \text{person capacity of a bus route or bus lane at its maximum load point under prevailing conditions (p/h)}; \]

\[ P_{max} = \text{maximum allowed passenger loading per bus (p/bus)}; \]

\[ f_{mlp} = \text{bus frequency on the route or the bus lane at its maximum load point (buses/h); and} \]

\[ PHF = \text{peak hour factor}. \]

High-speed bus service on busways and bus/HOV lanes should not allow standees, so capacity calculations should assume that every passenger may be seated.

The person capacity of a bus route or bus lane, in terms of number of boarding passengers during the analysis period, may be considerably greater than the person capacity given by Equation 2-7, if typical passenger trip lengths are short relative to the length of the bus route or bus lane. The maximum person capacity of a bus lane at its maximum load point is determined by the bus lane’s maximum vehicle capacity:

\[ P_{mlp, max} = P_{max} B(\text{PHF}) \]

\textit{Equation 2-8}

where:

\[ P_{mlp, max} = \text{maximum person capacity of a bus route or bus lane at its maximum load point (p/h); and} \]

\[ B = \text{bus lane vehicle capacity (bus/h)}. \]

Figure 2-8 shows how the door configuration and number of loading areas increase the maximum load point capacity. The left vertical scale applies to through-station operations where 50 percent of all passengers board at the heaviest stop. The right vertical scale applies to a single-station situation where all riders board at the major stop, such as at a CBD bus terminal. This figure can be used to estimate the number of passengers per hour that can be accommodated by various numbers and types of loading areas. It can be seen that increasing the number of doors available for boarding (e.g., by using pre-paid fares at busway stations or through use of smart card technology) greatly increases a busway’s person capacity.
Figure 2-8
Typical Busway Line-Haul Passenger Volumes

NOTE: PHF = 0.67. Six-channel configurations assume 60-passenger articulated buses.

Reference: [3]
2.3. Design Controls and Criteria

2.3.1. DESIGN VEHICLE

Figure 2-9

Turn Template: 40-ft Intercity Bus

- Assumed steering angle is 38.7°
- CTR = Centerline turning radius at front axle

Reference: [1]
Figure 2-10

Turn Template: 45-ft Intercity Bus

Reference: [1]
Figure 2-11

Turn Template: City Transit Bus

Path of left front wheel

Path of front overhang

Path of right rear wheel

- Assumed steering angle is 41°
- CTR = Centerline turning radius at front axle

Reference: [1]
Figure 2-12

Turn Template: Articulated Bus

Reference: [1]
2.3.2. DESIGN DRIVER

The identification of a design driver impacts several design elements for a transit-related facility. Design drivers are typically defined by their experience with the facility being considered. For example, commuters would be more familiar with an HOV lane than non-commuters. In addition, professional bus drivers are usually considered to be more aware of potential conflicts on a roadway than other motorists. In most cases, roadways and HOV facilities are designed for the unfamiliar driver who has had no professional training. Exceptions to this approach may be made on busways or other HOV lanes that will be restricted to buses or authorized vehicles.

Table 2-10
Examples of Typical Design Speeds for HOV Facilities

<table>
<thead>
<tr>
<th>Type of HOV Lane</th>
<th>Typical Design Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reduced</td>
</tr>
<tr>
<td><strong>Separate Right-of-Way</strong></td>
<td></td>
</tr>
<tr>
<td>Bus-Only</td>
<td>80 km/h (50 mph)</td>
</tr>
<tr>
<td>Bus and HOVs</td>
<td>60 km/h (40 mph)</td>
</tr>
<tr>
<td><strong>Freeways-HOVs</strong></td>
<td></td>
</tr>
<tr>
<td>Barrier separated</td>
<td>80 km/h (50 mph)</td>
</tr>
<tr>
<td>Concurrent flow</td>
<td>80 km/h (50 mph)</td>
</tr>
<tr>
<td>Contraflow</td>
<td>40 km/h (30 mph)</td>
</tr>
</tbody>
</table>

Reference: [5]

2.3.3. DESIGN SPEED

Roadway alignment design features are impacted by the designated design speed of the facility. In most cases, the design speed of an HOV facility on a freeway will be the same as that used on the adjacent general-purpose lanes. There may be limited instances where the design speed of the HOV lane is lower than the adjacent general-purpose lanes, however, due to the geometrics of the HOV facility or other limitations. The design speed for bus and HOV facilities on separate rights-of-way, which do not have adjacent general-purpose lanes, are usually based on the facility functional classification, topography, and adjacent land uses.

The designated design speed relates to the design features the HOV facility are expected to accommodate as noted in Chapter 2 of the AASHTO Green Book [1]. Further, the design speed should accommodate the vast majority (85 percent) of users. For example, concurrent flow HOV lanes should be expected to have the same design speed as the adjacent freeway lanes. A ramp meter HOV bypass lane will obviously have lower speed expectations.
AASHTO recommends design speeds of 100 km/h to 110 km/h (60 mph to 70 mph) on most urban freeways. Table 2-10 summarizes the design speeds typically associated with various types of HOV lanes. This information is provided to give a general idea of potential design speeds. The design speed for a specific facility should consider the anticipated user groups, the use of on-line and off-line stations, gradients, and local conditions. For example, in New York State, the design speed for freeway HOV lanes is based on the maximum off-peak speed observed in the general-purpose lanes unless other circumstances prevent such a speed being used.

### 2.3.4. ROADWAY ALIGNMENT GEOMETRY

A number of geometric factors should be considered in the design of a freeway HOV facility. Elements to be examined often include horizontal clearance, vertical clearance, stopping sight distance, superelevation, cross slope, horizontal curvature, vertical curvature, and gradient. The design recommendations, standards, and guidelines of AASHTO, ITE, individual states, and other groups should be used in determining these features for a specific HOV project. Each of these elements is discussed briefly in this section.

- **Horizontal Clearance.** There is a good deal of variance in the horizontal or lateral clearance with existing HOV lanes. As a minimum, at least a 0.6 meter (2 foot) lateral clearance should be provided to adjacent barriers, columns, or other obstructions for both HOV and general-purpose traffic lanes, although 1.2 meters (4 foot) is desired. Exceptions to this minimum should be considered only in temporary situations, such as construction or reconstruction of a facility where speeds are reduced, or for very short distances where other options do not exist.

- **Vertical Clearance.** The height of the tallest vehicle anticipated to operate in the HOV facility should be used to determine the vertical clearance. As discussed previously, buses are usually the tallest vehicle using an HOV lane. As a result, buses are commonly used to determine the vertical clearance. In the case of HOV lanes on freeways, the standard 4.9 meters (16 feet) used for the adjacent freeway lanes will also be used for the HOV lane. States can add 0.15 meter (0.5 ft.) if desired. This same standard is also commonly used with HOV facilities on separate rights-of-way, unless special limiting conditions exist.

- **Stopping Sight Distance.** The design of an HOV facility should provide adequate sight distance for a bus, van, or car to come to a controlled stop. As noted previously, the automobile is usually used as the design vehicle for determining stopping sight distance. AASHTO guidelines should be used in determining stopping sight distances for various travel speeds. The stopping sight distance should be checked if barriers are used as they may restrict the stopping sight distance.

- **Superelevation.** Superelevation rates should be applicable to curvature over a range of design speeds. Buses and vans, which have a higher center of gravity than passenger automobiles, typically require slightly higher superelevation rates. Where a curve radius cannot be increased, a higher rate of superelevation should be considered since vehicles with high centers of gravity require additional superelevations to avoid rolling over. AASHTO guidelines should be used to determine the appropriate superelevation of a specific HOV facility.

- **Cross Slope.** The cross slope of an HOV lane on a freeway is often the same as the cross slope of the adjacent general-purpose freeway lanes, which is commonly 2.0 percent. An HOV lane located in the center median of a freeway may straddle the roadway crown, however. In this case, the HOV lanes may be crowned to provide a 2.0 percent cross slope to both sides. The standard 2.0
percent cross slope is also used with busways and HOV lanes in separate rights-of-way. AASHTO guidelines should be used to determine the appropriate cross slope for a specific project.

- **Horizontal Curvature.** Horizontal curvature is based on the relationship of design speed, pavement side friction, and superelevation. The horizontal alignment of an HOV facility should be designed to ensure that curves can be safely negotiated by all design vehicles, including buses. AASHTO and state guidelines should be used to determine the appropriate horizontal curvature for a specific HOV facility. Consideration may need to be given to providing extra lateral lane width on curves for buses or semi-trucks on part-time HOV facilities.

- **Vertical Curvature.** The length of vertical curvature depends on stopping sight distance, eye height and gradient. HOV lanes on freeways typically follow the existing vertical curvature of the facility. For busways and HOV facilities on separate rights-of-way, K-factors are used to determine the necessary vertical curvature. K-factors represent the rate of vertical curvature and depend on design speed and the factors cited above. The length of a curve is determined by multiplying the K-factor by the algebraic difference in grade. Vertical curves longer than the minimum are desired. AASHTO and state guidelines should be used in determining the appropriate K-factor for a specific HOV facility.

- **Gradients.** AASHTO provides guidelines for gradients on freeways and roadways. These guidelines can also be applied to HOV facilities on freeways and in separate rights-of-way. Consideration should be given to the operating characteristics of the vehicles anticipated to use the HOV lane to ensure the facility functions safely. For example, a fully loaded bus will operate at slower speeds than an automobile on a sustained grade. The AASHTO Green Book (1) indicates that maximum grades of about 5 percent are considered appropriate for a design speed of 110 km/h (65 mph) and maximum grades of 7 to 12 percent for design speeds of 50 km/h (30 mph), depending on topography.

### 2.4. References


