CHAPTER 10
STATION CAPACITY

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1. INTRODUCTION

CHAPTER OVERVIEW

Transit stops, stations, and terminals (generically referred to as *stations* in this chapter) are the locations where passengers board, alight from, and transfer between transit vehicles. They range in size and complexity from simple streetside bus stops to large intermodal terminals, such as New York's Grand Central Terminal.

Chapter 10 of the *Transit Capacity and Quality of Service Manual* (TCQSM) discusses the features and elements of transit stations and provides methods for estimating their design requirements.

Organization of Chapter 10.

- The remainder of Section 1 introduces concepts applied throughout Chapter 10.
- Section 2 describes the various station types and typical configurations.
- Section 3 presents fundamentals of passenger circulation and introduces the concept of pedestrian level of service.
- Section 4 discusses issues related to vehicular circulation as it relates to station design and performance.
- Section 5 explores the various station elements and describes methods for analyzing their capacities.
- Section 6 presents applications of analytical methods to station elements.
- Section 7 provides examples of calculations for station capacity and sizing.
- Section 8 is a list of references used to develop the material in the chapter.
- Appendix A provides substitute exhibits in metric units for Chapter 10 exhibits that use U.S. customary units only.

HOW TO USE THIS CHAPTER

Sections 1 and 2 provide general concepts and background information about transit stations that will be useful to transit agency and consultant staff who are new to planning, designing, and operating these facilities.

Section 4 provides background information about transit, automobile, and bicycle circulation and parking facilities at a station that is relevant for non-technical audiences, as well as guidance on designing these facilities that is directed more toward facility planners and designers.

Section 6 describes potential applications of this chapter's material to planning and designing transit stops and stations, along with the role of simulation. The earlier subsections in this section are relevant for a broader audience, while the sections on comprehensive analysis and pedestrian microsimulation are directed toward facility planners and designers.

Section 3 provides pedestrian circulation and level of service concepts that analysts will ideally be familiar with prior to applying the computational methods in Section 5. Section 7 provides example calculations based on the Section 5 methods. These sections are directed to readers who will be directly involved in sizing station elements.

OTHER RESOURCES

Other TCQSM material related to station capacity includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- The "Passenger Load" section of Chapter 5, Quality of Service Methods, which presents information on the amount of space taken up by passengers holding or carrying various items;
- Chapter 9, Ferry Transit Capacity, which refers readers to this chapter for information on sizing ferry terminal elements; and
- The manual's CD-ROM, which provides links to the electronic versions of the TCRP reports referenced in this chapter.

STATION DESIGN CAPACITY

Design capacity is determined by passenger demand volumes under typical peak-period conditions, additional demand that builds during service disruptions and special events, and emergency evacuation situations. Either peak-period demand or emergency evacuation needs may drive the design of a specific station element, and both types of conditions should be evaluated during station planning and design. Specific requirements for addressing emergency evacuation contained in the National Fire Protection Association (NFPA) standard for fixed-guideway transit and passenger rail stations (NFPA 130, *1*) are reviewed in this chapter.

Either peak-period or emergency evacuation needs may drive the design (required capacity) of a specific station element.

Research has shown that a breakdown in pedestrian flow occurs with dense crowding of pedestrians, resulting in restricted and uncomfortable movement (*2*). For this reason, many of this chapter's methods for sizing station elements for peak-period conditions are based on maintaining a desirable pedestrian level of service (LOS), rather than designing for maximum pedestrian capacity and a less desirable service level.

In larger stations and terminals, the various pedestrian spaces interact with one another such that pedestrian circulation may better be evaluated from a systems perspective. Simulation models can assess route choice and the complex interaction of pedestrians to predict emergent crowd dynamics, including the impact of queue spillback on upstream facilities. These models can be used to size internal spaces within a station, and their application is discussed in this part of the TCQSM. For stations with frequent transit service, the time required to clear a station platform before the arrival the next train or bus may be a critical consideration. Even where services do not run on a close headway, platform clearance time is a useful measure of passenger convenience.

ACCESS FOR PERSONS WITH DISABILITIES

The needs of persons with disabilities should be considered throughout the process of planning and designing transit station facilities. Both physical and cognitive disabilities should be considered and provisions for addressing these are referenced throughout the chapter. The Americans with Disabilities Act (ADA) requires all new transit stations in the United States to be accessible to persons with disabilities. It also requires that key stations in existing systems be made accessible and that major remodeling of any station incorporate accessible features. The act includes provisions

Station design must also consider the needs of persons with disabilities.

both for persons with mobility impairments, who may use wheelchairs, and for persons with other sensory or cognitive impairments, including visual and hearing limitations.

http://www.access-board.gov/ada-aba/ada-standards-dot.cfm

Specific regulations for transit stations, including accessible route provision, architectural features, and accessible communications elements and features are contained in the *ADA Standards for Transportation Facilities* (*3*). These issues should be addressed at each stage of the transit station planning and design process. For example, opportunities may be found to incorporate ramps into the design that serve passengers with disabilities and also benefit movement by other passengers. Elements addressing the needs of persons with disabilities can be worked into a facility's overall design.

EMERGENCY EVACUATION

NFPA 130 establishes standards for the evacuation of fixed guideway transit and passenger rail stations.

Provisions for evacuation during an emergency are an important consideration in the design of transit stations and terminals. Design and performance standards for emergency evacuation are presented in NFPA 130.

The key provisions of NFPA 130 (2010 edition) related to station capacity are summarized as follows (*1*):

- Sufficient exit capacity shall be provided to evacuate platform occupants (including those on trains) from platforms in 4.0 min or less.
- Sufficient exit capacity shall be provided to permit evacuation from the most remote point on a platform to a point of safety in 6.0 min or less.
- A second means of egress with at least 44-in. (1.12-m) clear width and remote from the major egress route shall be provided from each platform.
- The maximum distance to an exit from any point on a platform shall be not more than 325 ft (100 m).
- Escalators shall not provide more than half of the exit capacity from any level (except in specific circumstances), and one escalator at each level, resulting in the most adverse exiting condition, shall be assumed to be out of service and unavailable for egress.

NFPA 130 specifies facility element capacities and pedestrian speeds to be used in evacuation analysis.

The current edition of NFPA 130 contains more detailed information on the evacuation standards and calculation procedures. In particular, the standard specifies design capacities and pedestrian travel speeds that should be used for evacuation analysis. These capacities and speeds are often different than those presented in this chapter for designing daily passenger circulation.

Evacuation analysis should be performed in conjunction with analysis and planning for daily circulation patterns. While in some cases the overall requirements for evacuation exceed the requirements for daily circulation, the two circulation patterns are dramatically different and each may result in different requirements at particular points in a station. While evacuation requirements must be satisfied, this represents a rare circumstance, with daily circulation defining the passengers' normal experience; hence, evacuation should not be the only consideration in station design.

The requirements of daily passenger circulation and emergency evacuation should be considered in tandem both in overall station planning and in the design of individual station systems, such as vertical circulation or mezzanines, and in the design of individual elements. One example of overall station planning in which both requirements need to be addressed is the issue of center versus side platforms. In more

complex or higher-capacity stations, the number of platforms may also need to be addressed from both daily use and emergency perspectives. The number and configuration of platforms directly affects potential platform access, particularly when vertical circulation is required to access and egress platforms.

When multilevel stations are considered, the typical peak-period circulation pattern may differ greatly from an emergency situation. For example, the daily flow pattern in a particular rail transit station may emphasize intra-station transfers and large numbers of passengers passing through on trains without boarding or alighting. During an emergency, the same station would experience much higher exiting volumes than normal, including the normal exiting volumes, those passengers who normally remain on trains passing through the station, and those passengers who transfer at the station but normally do not exit there.

Circulation elements that are normally used for entering a station can largely be used for exiting during an emergency condition. Thus, stairs normally used by entering passengers can be used by those exiting, and inbound-moving escalators can be turned off or switched to the outbound direction. Some consideration should also be given to the need for emergency crews to enter a station as it is being evacuated.

SECURITY

Public security in transit stations has important consequences for transit ridership. Both actual security, as measured by reported and unreported incidents, and perceived security are important for passengers. If passengers feel that a stop or station is unsafe, they will try to avoid it, even if the actual level of crime is low. Law enforcement personnel, video cameras, and emergency call boxes (see Exhibit 10-1) can play an active role in station security. However, factors such as visibility, lighting, and the presence of other people also play key roles. Visibility applies both within an enclosed station and from a street or other nearby land uses into a station.



(a) Law enforcement presence (Tacoma)



(b) Video surveillance (New York)

Exhibit 10-1
Example Transit Station Security Elements

A number of world cities have experienced acts of terrorism on transit properties, including within stations. *TCRP Synthesis 80: Transit Security Update* (*4*) provides summaries of strategies that transit agencies use effectively to reduce crime, improve passengers' perceptions of security, and address terrorist threats. The *TCRP Report 86: Public Transportation Security* series (*5*) also provides information on various aspects of transit security developed in the wake of the September 11, 2001 terrorist attacks. Finally, the FTA's Safety and Security website (*6*) provides another useful resource.

2. STATION TYPES AND CONFIGURATIONS

OVERVIEW

Various types of transit stops, stations, and terminals provide service tailored to the specific needs of a transit system or a particular locale. These facilities often have common features and elements, but they may display unique characteristics. The basic types of transit stops, stations, and terminals are presented in this chapter, along with examples of typical passenger amenities that are provided.

BUS STOPS

Most bus stops are located along streets and consist of a waiting area integrated with the public sidewalk, signage to mark the bus stop, and, in some cases (depending on passenger volume, available space, and available power), small-scale passenger amenities such as a bench, small shelter, bicycle parking, printed schedule and route information, or real-time bus-arrival displays. Lighting, either from adjacent street lighting or built into a shelter, is desirable to enhance nighttime security.

Bus stops can also be located on- or off-street in conjunction with transit centers, rail transit stations, or intermodal terminals; these are discussed in the "Transit Centers" section that follows.

From a capacity standpoint, the key element is sizing the waiting area appropriately so that passengers waiting for buses neither unduly restrict pedestrian movement on the adjacent sidewalk, nor hinder passengers alighting from arriving buses. The methods given in Section 5 for passenger waiting areas can be used to determine the space needed to accommodate the anticipated peak-passenger demand, while the method for sidewalks can be used to determine the space needed to accommodate sidewalk pedestrian flow (with consideration of maintaining a minimum clear width for wheelchair movement).

In some cases, bus stops may be located on boarding islands within the street or within a transit center. In these cases, it is particularly important to provide sufficient waiting area so that passengers do not spill over into the adjacent roadway.

Stops that comply with the ADA will provide (*3*):

- A firm, stable surface;
- A clear length of 96 in. (2440 mm), measured perpendicular to the curb or roadway edge, and a clear width of 60 in. (1525 mm), measured parallel to the roadway, to the extent that the construction specifications are within a public entity's control; and
- An accessible connection to a street, sidewalk, or pedestrian path.

The ADA also specifies standards for bus stop slope, sign legibility, and (if provided) clear space within bus shelters (*3*).

TCRP Report 19: Guidelines for the Location and Design of Bus Stops (*7*) provides guidance on designing bus stops to accommodate transit vehicles; many larger transit agencies have developed their own standards specific to their bus fleet and local conditions. TCQSM Chapter 6, Bus Transit Capacity, describes the advantages and

disadvantages of near-side, far-side, and mid-block on-street bus stops on pages 6-11 and 6-12. Bus stops can be placed on the near side of an intersection, on the far side, or mid-block. In all cases, good access to the sidewalk and crosswalk network is essential.

TRANSIT CENTERS

The term *transit center* is normally applied to facilities where multiple bus routes converge, offering transfer opportunities between routes and, frequently, layover area for bus routes that terminate at the center. The term can also apply to intermodal stations that may combine transfers between local buses with opportunities to transfer to rail and other modes. Both types of facilities are normally located wholly or partially off-street. Good wayfinding information is essential for passengers to find their way to their transfer connection, and should also consider the needs of persons with disabilities. Amenities beyond those that might be found at an on-street bus stop can include a larger or more elaborate shelter, climate-controlled waiting areas, ticket sales, concessions, transit system and neighborhood maps, secure bicycle parking, taxi stands, restrooms, and a passenger pick-up/drop-off ("kiss-and-ride") area. Transit centers associated with intermodal stations in suburban areas might also provide a park-and-ride facility. Additional security features could include video surveillance or on-site security staffing or policing. Bus operations elements frequently include the provision of a driver break room and restrooms, along with parking spaces for field supervisors.

As with on-street bus stops, the key passenger capacity elements involve providing sufficient waiting area at individual stops and sufficient circulation area to allow passengers to quickly move between stops or the transit center entrances and exits. Depending on the surrounding land uses and the bus arrival pattern at the center (e.g., timed transfers), waiting or transferring may be significantly more dominant. The methods given in Section 5 of this chapter can be used to size waiting and circulation areas.

Bus capacity—in the form of providing sufficient bus bays for loading and unloading passengers and providing layover berths for buses that end their route at the transit center—is also an important consideration for transit centers. The methods given in Section 4 of this chapter can be used to estimate the number of required bus berths; that section also discusses kiss-and-ride, park-and-ride, and bicycle access.

Some other aspects of transit center design are outside the scope of the TCQSM but should also be considered in the planning and design process. These include:

- Location of pedestrian crossings of vehicular roadways and means of directing pedestrians toward those crossings, which promotes both passenger safety and smoother transit vehicle operations.
- Bus turning radii, to ensure smooth transit vehicle operations.
- Locations of bus access points to the transit center relative to the adjacent street system, relative to pedestrian and auto (e.g., park-and-ride, kiss-and-ride) access points, and relative to the directions in which buses arrive and depart, to minimize traffic conflicts and bus delay.

Some larger transit agencies, such as in British Columbia, Canada (*8, 9*) and Copenhagen, Denmark (*10*), have developed architectural and engineering design guidance for transit centers. ADA requirements in the U.S. for bus stops and public

facilities (*3*), and corresponding local standards or best practice elsewhere, should also be incorporated into a transit center's design.

BUSWAY AND BRT STATIONS

Busway and bus rapid transit (BRT) stations are located along roadways or lanes dedicated for buses and are frequently larger and more elaborate than typical bus stops, but are often shorter than light rail stations. Like the busways they serve, these stations may be either off-street or on-street. The length of a busway or BRT station is generally 40 to 100 ft (12 to 30 m) but some extend to 400 ft (120 m) to serve multiple routes and services. Amenities may be limited, consisting of just a paved area and sign, or more elaborate, with shelters, seating, ticket machines, real-time bus arrival information, radiant heating, security features, and other amenities.

Busway stations may also require vertical circulation elements to avoid the need to have passengers cross a busway at-grade; these elements are also needed when the station itself is located above or below grade. Busway stations toward the outer end of a route may also provide park-and-ride lots. Busway stations in some South American cities (such as Bogotá, Curitiba, and Quito) are enclosed with fare collection at the station and high-level bus boarding.

Busway and BRT stations usually consist of side platforms boarded from the right side of the bus, but some center platform stations are used with boarding from the left side of the bus (this requires buses designed with doors on both sides, as are used in Cleveland and Eugene). Center platforms can also be used when a busway operates in a contraflow (i.e., left-side running) configuration, allowing the use of standard buses with right-side doors. Busway stations may have a single lane in each direction where all buses stop at each station, or a passing lane can be provided at stations to increase operational capacity and allow for multiple services that skip some stations.

Coordination between the design of BRT stations, vehicles, and guideways allows providing features that have the potential to increase both passenger convenience and the speed of boarding and alighting, reducing dwell times. Such features include level boarding, precision docking of buses, and wider doors on both buses and stations, where applicable.

As with other types of bus stops, the methods given in this chapter's Section 5 can be used to size a station's waiting and circulation areas. When off-board fare payment is used, Section 5 also can be used to evaluate the space required for passengers queued at ticket machines and the number of machines themselves. Section 5 also provides guidance on locating and sizing a station's vertical circulation elements.

Bus capacity—in the form of providing sufficient bus bays for loading and unloading passengers and (potentially) providing passing lanes for buses not stopping at the station—must also be considered in the station design. The methods given in Chapter 6 can be used to determine the number of bus bays required to achieve a desired operational reliability.

Design guidance on other aspects of busway and BRT stations can be found in several TCRP and FTA publications (*11–13*) and an APTA recommended practice (*14*). A European research project (*15*) has also developed best practices for integrating BRT stations into their surroundings.

LIGHT RAIL AND STREETCAR STATIONS

Light rail stations are typically 180 to 400 ft (55 to 120 m) long. Various platform configurations are possible, including center, side, or split on opposite sides of an intersection. Stations may be on-street, off-street, along a railroad right-of-way, on a transit mall, or as part of a transit center. High and low platforms have both been used, although the trend in recent years has been the increasing use of an intermediate height for platforms that is approximately 14 in. (0.35 m) above the top of the rail to match the floor height of low-floor light rail vehicles. Light rail stations usually include canopies over part of the platform, limited seating, and ticket vending machines. Other amenities could include climate-controlled waiting areas, concessions, transit system and neighborhood maps, secure bicycle parking, taxi stands, electronic information displays, restrooms, security features, kiss-and-ride, and park-and-ride. Fare collection on light rail systems is typically by the proof-of-payment system, so stations typically do not have fare gates or barriers.

Light rail stations located above or below grade, in freeway medians, and in locations where it is not desired to have passengers cross the tracks will also require vertical circulation elements and fences between tracks. ADA requirements pertaining to rail stations include the need to minimize the vertical and horizontal gap between platform and vehicle (except at stations where vehicles are intended to be boarded from the street or sidewalk). Other ADA requirements address platform slope, provision of detectable warnings at the platform edge, signage, public address systems, clocks, and track crossings (*3*).

The methods given in Section 5 can be used to size a light rail station's waiting areas, circulation paths, ticket machines, and vertical circulation elements. Some U.S. transit agencies that operate light rail have developed design standards for stations and a European research project (*15*) has developed best practices for integrating light rail stations into their surroundings.

Except where they are shared with light rail, modern streetcar stations or stops are typically shorter, narrower, and less elaborate than LRT stations, matching the streetcars' size and length. Streetcar lines are more likely to use adjacent sidewalks for boarding. Although any of the amenities associated with light rail can be applied to streetcar stops, the number or size of elements may be reduced.

HEAVY RAIL AND AGT STATIONS

Stations in heavy rail (rapid transit, metro) and automated guideway transit (AGT) systems are usually more elaborate than light rail or commuter rail stations. Due to the presence of third-rail power in most of these systems, and to discourage passengers from entering or crossing the trackway, these stations require high-level platforms. Some systems also use platform screen doors to control access to the trackway and/or maintain climate control on the platforms. Stations are most often located underground or elevated, and frequently have intermediate mezzanine levels between the street and platform levels. Both center and side platform configurations are used, and some stations have more than two tracks. Special configurations allow cross-platform transfers or reflect location-specific conditions. Heavy rail stations are generally 600 to 800 ft (180 to 240 m) long. AGT stations are often shorter, given the smaller trains used on these systems.

Most heavy rail stations have fare control arrays and enclosed paid zones, although some European systems use proof-of-payment systems. Depending on the fare payment system, fare-collection machines may be located both inside (e.g., addfare) and outside (e.g., fare purchase) the fare-paid area. Stations where a parking fee is charged may also have a parking fee payment machine inside the fare-paid area (to ensure people who park use the transit service). Many U.S. heavy rail stations provide a staffed station agent booth to monitor station activity and to answer passenger questions. Other station amenities can include security features, concessions, transit system and neighborhood maps, secure or staffed bicycle parking, electronic information displays, taxi stands, restrooms, kiss-and-ride, and (in suburban areas) park-and-ride. Underground stations may provide multiple exits. Good wayfinding information is needed to direct passengers—particularly those unfamiliar with the station—to the exit closest to their destination.

The methods given in Section 5 can be used to size the full range of station elements found in these types of stations, while Section 4 addresses kiss-and-ride, park-and-ride, and bicycle access. One difference to note is that when seating space on arriving trains is limited, passengers may choose to queue near the locations where the train doors will be, to maximize their chance of getting a seat. As a result, platform space will be used differently than when passengers expect to be able to get a seat or have no expectation of getting a seat. Section 6 describes the application of simulation to station planning and design, which is often necessary for high-volume, multiple-exit stations where there are many interacting passenger flows and activities.

COMMUTER RAIL STATIONS

Commuter rail stations range from suburban locations with one or two platforms, limited service, and relatively small passenger volumes to major urban terminals with many tracks and platforms offering a variety of local and express services to various destinations. Stations may use either center or side platforms, or a combination of both. Higher-volume systems tend to use high platforms, while lower-volume systems tend to use low or intermediate-height platforms. In some cases, passenger and freight trains share the same tracks. Horizontal clearance requirements for freight cars may be greater than those for passenger equipment and thus can impact platform height, platform offsets from the track, and the placement of platform features such as wheelchair ramps. Platforms can range from 300 to more than 1,000 ft (90 to over 300 m) long.

Passenger flow on commuter rail platforms can be more complex when multiple routes and services share the same platform and waiting areas. Where that is the case, not all passengers waiting on platforms will board a train when it arrives, leaving residual passenger volumes on platforms. Commuter rail cars typically have fewer doors than heavy rail cars and may fully load or unload at a single major terminal, increasing their boarding, alighting, and dwell times at those stations.

U.S. commuter rail systems often rely on park-and-ride as their primary access mode. Fares are typically purchased from machines or a ticket sales booth. Other station amenities can include a climate-controlled waiting area, concessions, secure bicycle parking, taxi stands, restrooms, kiss-and-ride, real-time train arrival information, and security features. Some commuter rail systems allow bicycles on board trains. As with

other types of rail stations, Section 4 addresses sizing station access features, while Section 5 addresses sizing passenger circulation and waiting area elements.

FERRY DOCKS AND TERMINALS

Ferry docks and terminals can vary from simple waterside facilities with limited shelters and relatively small passenger flow volumes to major terminals with multiple ferries receiving and discharging large numbers of passengers and vehicles. Since waterside locations are particularly exposed to the weather, protection from the climate can be an important factor in providing a good quality of travel. The effect of tides, changing river levels, and waves must be adequately addressed and pose unique challenges for passenger access, especially where extreme height changes are experienced, potentially requiring long or steep ramps to reach vessels.

As discussed in Chapter 9, Ferry Transit Capacity, a relatively structured system is required to process passengers from shore to vessel. This system encompasses fare collection, security checks, and passenger counting (to ensure that the number of passengers on board does not exceed the vessel's regulatory capacity), and to restrict access to potentially hazardous areas. This chapter's Section 5 can be used to size ferry terminal passenger circulation elements. *TCRP Report 152: Guidelines for Ferry Transportation Services* (*16*) provides additional guidance about ferry terminal elements.

INTERMODAL TERMINALS

The term *intermodal terminals* refers to a variety of stations and terminals that provide key transfers between transit modes. Combinations may include local bus, bus rapid transit, intercity bus, light rail, heavy rail, commuter rail, intercity passenger rail, ferry, or AGT. Such facilities may have a variety of other services and connections, including parking, drop-off, ticket vending, and information booths. Intermodal terminals are increasingly regarded as ideal locations for land use intensification and may be integrated with retail shopping, services, and entertainment. Because these facilities typically have many entrances and exits and potentially multiple levels, good wayfinding information is needed to direct passengers from entrances to their transit vehicle and vice versa. Because of the heavy passenger volumes using these facilities and the interactions between various terminal elements, simulation is typically used to model passenger movements through an intermodal terminal. Section 6 describes the role of simulation in terminal planning and design.

PASSENGER AMENITIES IN STATIONS

Passenger amenities are provided at a bus stop or transit station to enhance comfort, convenience, and security for transit patrons. Amenities include such items as shelters, benches, vending machines, trash receptacles, lighting, phone booths, art, and landscaping. Improvements to station amenities can reduce the perceived inconvenience of transferring and waiting time. Although the effect that a specific amenity may have on transit ridership is likely to be small, the cumulative impact of providing an overall good level of amenity may be significant.

Amenities at most bus stops or transit stations are placed in response to a human need or a need to address a local condition. Some advantages and disadvantages of

various passenger amenities are summarized in Exhibit 10-2. Examples of passenger amenities at transit stops and stations are illustrated in Exhibit 10-3.

Exhibit 10-2
Examples of Passenger Amenities at Transit Stations

Amenity	Advantages	Disadvantages
Shelters	• Provide comfort for waiting passengers • Provides protection from climate (sun, glare, wind, rain, snow) • Help identify the stop/station	• Requires maintenance, trash collection • Can be vandalized Visual impact on surroundings
Benches	• Provide comfort for waiting passengers • Help identify the stop/station • Lower cost compared to a shelter	• Require maintenance • Can be vandalized
Lean bars	• Provide some comfort for waiting passengers • Lower cost, less space, and less maintenance compared to benches	• Not as comfortable as benches • Require maintenance
Lighting	• Increases visibility • Increases passengers' perception of security • Discourages "after hours" use of facilities by indigents	• Requires power • Requires maintenance • Can be costly
Maps	• Provide information on how to use the transit system • Provide information on how to get to destinations in the vicinity	• Require periodic updating
Real-time arrival information	• Assures passengers that their bus/train is coming • Reduces perceived waiting time • Improves perception of service reliability	• Requires power and communications connections • Requires maintenance • Can be costly
Radiant heating	• Provides comfort for waiting passengers in cold climates	• Requires power • Requires maintenance • Can be costly and a potential liability
Vending machines and newsstands	• Provide services (e.g., food, drink, news) for waiting passengers • May produce revenue for transit system	• Increase maintenance through trash accumulation and spilled food/drink • May have poor visual appearance • Can be vandalized
Trash receptacles	• Provide place to discard trash • Keep the stop/station and its surroundings clean	• May be costly to maintain • May be used by customers of nearby land uses • May have a bad odor • May create security issues
Telephones	• Convenient for transit patrons • Provides access to transit information and emergency services	• May encourage loitering • May encourage illegal activities • Widespread usage of mobile phones may reduce their need
Art	• Creates a more aesthetically pleasing station environment	• May be perceived as wasteful by transit critics

Source: Derived from Texas Transportation Institute (*7*), updated for the TCQSM 3rd Edition.



(a) Shelter & bench (Denver)



(b) Telephones (Denver)



(c) Vending machines (Brisbane, Australia)



(d) Lighting (Cleveland)



(e) Trash receptacle (Albuquerque)



(f) Art (Los Angeles)

Exhibit 10-3
Passenger Amenities Illustrated

The space needed for passenger waiting at transit stops and stations should account for space taken by shelters, benches, information signs, and other amenities. Amenities at bus stops and transit stations should be placed so that they do not interfere with the landing area for a lift or ramp for people with disabilities and so that their spacing or placement does not constrict movement by wheelchair users.

Placement of passenger amenities at bus stops and in stations impacts space required for circulation and waiting areas.

When shelters are provided at light rail and busway stations, they typically do not cover the entire station platform. The extent of coverage depends on local climate, impacts on surrounding properties, circulation, and passenger waiting patterns. If most passengers wait for trains or buses on one platform and alight on the other platform, then canopies may be provided only on the side of the station where passengers wait, or there may be fewer or smaller canopies on the alighting side of the station.

3. PASSENGER CIRCULATION

INTRODUCTION

This section introduces the concept of pedestrian level of service (LOS) and it describes the basic elements that might be found in a transit station, working from the outside of the station inward to the transit platform. Computational methods for sizing station elements are presented in Section 5.

PEDESTRIAN LEVEL OF SERVICE

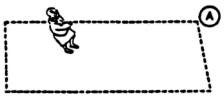
Pedestrian levels of service provide a useful means of evaluating the capacity and comfort of an active pedestrian space. Pedestrian LOS thresholds related to walking are based on the freedom to select desired walking speeds and the ability to bypass slower-moving pedestrians. Other considerations related to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, and to maneuver without conflicts with other pedestrians or changes in walking speed.

Levels of service for pedestrian circulation areas are based on available standing space, perceived comfort and safety, and the ability to maneuver from one location to another. LOS letters range from A to F, with A representing an unimpeded condition and F representing an undesirable condition in which pedestrian movement is severely constrained. Pedestrian capacity—the maximum number of pedestrians that can pass a point in a given period of time—is represented by the threshold between LOS E and F. However, station design for typical conditions is usually based on maintaining a desirable (more comfortable) pedestrian LOS, rather than designing for maximum pedestrian capacity.

The thresholds between each LOS letter correspond to a particular average space available to each pedestrian. The pedestrian space corresponding to a desired LOS can therefore be used in planning and designing features such as platform size, number and width of stairs, corridor width, and so forth, by sizing these elements to provide the desired LOS at a particular pedestrian flow.

Exhibit 10-4 illustrates the space available to walking pedestrians at various levels of service. At the highest levels of service, pedestrians can move relatively freely at or near their desired speed, and following their desired path. At lower levels of service, pedestrians' freedom of movement becomes more and more constrained. The situation is similar in queuing areas, illustrated in Exhibit 10-5. At the highest levels of service, standing pedestrians have relatively high levels of personal space, while others can circulate between the standing pedestrians. As LOS gets worse, standing pedestrians become packed together and circulation becomes difficult or impossible.

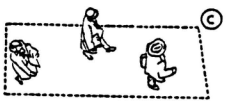
Planning or designing a pedestrian space for typical operating conditions seeks to balance pedestrian comfort (LOS) against other practical needs, such as construction and maintenance costs. The choice of a design LOS should also consider how long pedestrians will experience the condition: for example, persons will tolerate being packed together on an elevator longer than they will waiting on a station platform.



LEVEL OF SERVICE A
Walking speeds freely selected; conflicts with other pedestrians unlikely.



LEVEL OF SERVICE B
Walking speeds freely selected; pedestrians respond to presence of others.



LEVEL OF SERVICE C
Walking speeds freely selected; passing is possible in unidirectional streams; minor conflicts for reverse or cross movement.



LEVEL OF SERVICE D
Freedom to select walking speed and pass others is restricted; high probability of conflicts for reverse or cross movements.



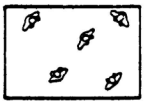
LEVEL OF SERVICE E
Walking speeds and passing ability are restricted for all pedestrians; forward movement is possible only by shuffling; reverse or cross movements are possible only with extreme difficulty; volumes approach limit of walking capacity.



LEVEL OF SERVICE F
Walking speeds are severely restricted; frequent, unavoidable contact with others; reverse or cross movements are virtually impossible; flow is sporadic and unstable.

Source: HCM 2000 (*17*).

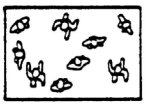
Exhibit 10-4
Illustration of Walkway Levels of Service



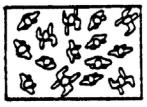
LEVEL OF SERVICE A
Standing and free circulation through the queuing area possible without disturbing others within the queue.



LEVEL OF SERVICE B
Standing and partially restricted circulation to avoid disturbing others within the queue is possible.



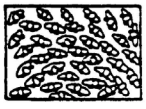
LEVEL OF SERVICE C
Standing and restricted circulation through the queuing area by disturbing others is possible; this density is within the range of personal comfort.



LEVEL OF SERVICE D
Standing without touching is impossible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is discomforting.



LEVEL OF SERVICE E
Standing in physical contact with others is unavoidable; circulation within the queue is not possible; queuing at this density can only be sustained for a short period without serious discomfort.



LEVEL OF SERVICE F
Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely discomforting; no movement is possible within the queue; the potential for pushing and panic exists.

Source: HCM2000 (*17*).

Exhibit 10-5
Illustration of Queuing Area Level of Service

Pedestrian performance is often reported in terms of the average LOS of a space over time (typically over the busiest 15-min period of activity). Where the nature of pedestrian movement is heavily pulsed (for example, in areas adjacent to train alighting activity), reporting based on longer time periods may obscure pedestrian circulation problems. The average LOS experienced by individual passengers may be reported instead of (or in addition to) a time average LOS, although conversely, this metric may exaggerate pedestrian circulation concerns. It is, therefore, appropriate in many cases to review pedestrian LOS in the context of other useful reporting metrics such as volume-to-capacity ratio, passenger journey time, platform clearance times, or average queuing delay time. These metrics are described in more detail later in this chapter.

STATION ACCESS

Information Provision

The impact of information provision on station capacity is felt at locations where pedestrians have to stop to orient themselves or to read needed information (e.g., the track assigned to a particular train). These stopped pedestrians create an impediment to the flow of other pedestrians, thereby reducing the capacity of a walkway or other station circulation element.

Clarity of Station Layout

In more complex transit stations and terminals, passengers' ease in finding their way around the station becomes important. While signage is an indispensable element in wayfinding, station layout and design can do much to make a station more understandable and easier to navigate. For example

- Clear, unobstructed sight lines can provide visual connections to other levels and between points inside and outside the station;
- Alternate symbols, finishes, colors, and shapes can distinguish between alternate routes or services; these should be used consistently systemwide;
- Center platforms allow passengers who have missed their intended stop to easily reverse direction and do not require passengers to identify the correct platform before reaching it, reducing confusion;
- Tactile signage and audible information offers direction and information to persons with visual impairments;
- Cross-platform transfers for dominant passenger movements reduce passenger demand on vertical circulation elements, shortens passenger walking distances, and makes connections easier to find; and
- The same design elements that contribute to wayfinding can also contribute to real and perceived safety within the station and passenger comfort.

Signage and Information Displays

Station signage, illustrated in Exhibit 10-6, provides information to passengers both waiting in the station and arriving on transit vehicles. Static and electronic signs can direct passengers to loading areas or platforms for various transit services, to station exists and nearby destinations, and to emergency evacuation routes. System maps,

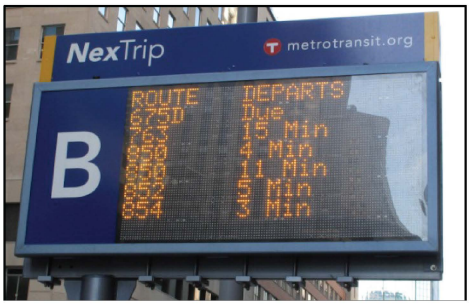
schedules, fare information, and neighborhood maps provide information for passengers. While most stations or stops will include at least minimal signage, more complex stations require more extensive wayfinding systems. Signage and information is particularly important to the occasional transit passenger, but reinforces the transit experience and options for all passengers.

Signage, along with other station elements and finishes, provides an opportunity at "branding" of a particular transit service or system. Consistent elements and styles become recognizable symbols of the service recognized by the public and can impart a modern and comfortable image for the station and the service.

Signage should be accessible to persons with disabilities, including Braille and audible information, and should be placed so that it is accessible to wheelchair users.



(a) Posted system and area information



(b) Real-time schedule information



(c) Wayfinding information



(d) Audible schedule information



(e) Emergency call box



(f) Elevator availability information

Exhibit 10-6
Signage and Communication System Examples

Photo locations:
(a) San Diego
(b) Minneapolis
(c) New York
(d) Minneapolis
(e) Boston
(f) San Francisco

Public Address Systems

Public address systems may be provided in stations both for public information and for security. A public address system can be activated by on-site personnel or it can be connected to a remote central control facility. It may be combined with passenger call boxes allowing passengers to call for information or emergency assistance. Video monitors allow staff to monitor conditions and events in the station and to record them for law enforcement purposes. The presence of video cameras and call boxes also acts as a deterrent to some crimes. The ADA requires that where public address systems are used, "the same or equivalent information shall be provided in a visual format" (*3*).

Doorways

Doorways (Exhibit 10-7) limit the capacity of a walkway by imposing restricted lateral spacing. Because of this restriction on capacity, doorways will impact the overall capacity of a pedestrian walkway within a transit station, and therefore will require additional design considerations. Doorways are required to comply with the ADA Accessibility Guidelines. Revolving doors or gates are not considered part of an accessible route.

Exhibit 10-7
Doorway Example
(New York)



The effect of doorways on pedestrian flow will depend on the headway (time) between pedestrians. When a pedestrian reaches a doorway, there must be sufficient time-headway separation to allow that pedestrian to pass through the doorway before the next pedestrian arrives. If time-headways between successive pedestrians are too close, a pedestrian queue will develop. The capacity of a doorway is therefore determined by the minimum time required by each pedestrian to pass through the entrance.

At exterior entrances, the provision of canopies extending beyond doorways can provide a useful space for pedestrians to get out of rain or snow and put down umbrellas before entering or after exiting. However, if incorrectly sized, these can attract people to stand in such a way that they block passage in and out of the entrance.

Fare Purchase

Higher-capacity transit services typically require passengers to purchase their fare before boarding a transit vehicle. Fare purchase is one of the least-standardized elements of transit service, as it depends on the particular characteristics of the transit system's fare structure and the equipment used to purchase tickets (Exhibit 10-8). There are frequently several steps involved in the process and may include:

- Selecting a ticket type (e.g., child, adult, senior);
- Selecting a fare type, destination, or amount (e.g., one-way, round-trip, all-day, two zones, airport station, $2.50);
- Selecting the number of tickets desired;
- Selecting a payment method (cash, card);
- Making the payment; and
- Receiving the ticket(s) and possibly a receipt or change.

The number of steps involved, the clarity of the sequence of the steps, the ease of determining the required fare, and the familiarity of the user with the transit system and the fare-purchasing process all play a role in determining how long it takes to process a transaction. As one example, WMATA has used 2.5 p/min as an average fare purchasing rate for its machines in station planning studies (*18*). Ticket machines that incorporate video displays should be designed and located so that the display is legible under a variety of conditions (Exhibit 10-8c). Ticket vending machines must be made accessible for persons with disabilities, including Braille writing, audible information, and other design features.



(a) Portland



(b) Baltimore



(c) Blocking glare in Seattle

Exhibit 10-8
Fare Machine Examples

At busier heavy rail stations, several ticket machines are typically provided to handle peak-passenger demand for tickets. At light rail and bus rapid transit stations, at least one ticket machine is provided on each platform, but some redundancy is desirable in case one machine is out of service. Staffed ticket booths are used at older heavy rail stations and at many commuter rail stations. Where distance-based fares are used,

addfare machines are usually placed inside the fare-paid area so that passengers with insufficient value left on their ticket can pay the balance of the fare.

Fare Control

Faregates limit the capacity of a circulation route by imposing restricted lateral spacing and by requiring pedestrians to perform an activity that consumes additional time. Faregates are typically applied at heavy rail stations to control fare payment. They are applied to a lesser extent at commuter rail, light rail, and bus rapid transit stations, due to the proof-of-payment system associated with most of these systems. Faregates are required to comply with the ADA Accessibility Guidelines, although turnstiles and some types of gates are not considered part of an accessible route.

Exhibit 10-9 illustrates the placement and operation of faregate configurations in a transit terminal. There are three different types of faregates applied in stations:

- Free admission (a barrier only),
- Mechanical coin- or token-operated, and
- Automated (using contactless smart cards or magnetic farecards).

Automated faregates using magnetic stripe farecards came into wide use starting in the 1970s, while contactless smart card systems were pioneered in Hong Kong in 1997 grew in usage throughout the 2000s. Both technologies can accommodate a variety of fare types (e.g., distance-based fares, peak and off-peak fares) and can generate useful passenger flow data. Free-admission gates (e.g., turnstiles or swinging gates) are used when no fare is collected, but passenger counts are desired. Some agencies—particularly ferry systems—use staff to check and collect tickets, but this form of fare collection is little used for rail transit applications in North America and Western Europe, except during special event situations, such as at sports stadia. Systems using automated faregates generally also have a channel available next to the station agent's booth to accommodate checking users with non-standard tickets (e.g., visitor passes with scratch-off dates).

Exhibit 10-9
Faregate Examples



(a) New York



(b) San Francisco

The effect of faregates on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a faregate, there must be sufficient time separation to allow that pedestrian to pass through the faregate before the next pedestrian arrives. If the times between successive pedestrians are too close, a pedestrian queue will develop. The capacity of a faregate is therefore determined by the minimum time required by each pedestrian to pass through.

Despite increasing concern for security, screening is not currently undertaken in most transit stations. However, planners of new stations or those in particularly sensitive locations may wish to make provision for screening either in the future or on an as-needed basis.

HORIZONTAL CIRCULATION

Walkways

The capacity of a walkway is controlled by the following factors:

- Pedestrian walking speed;
- Pedestrian preferred density;
- Pedestrian characteristics; usage of baggage, strollers, or bicycles; and presence of wheelchair users; and
- Effective width of the walkway at its narrowest point.

Speed

Normal walking speeds of pedestrians vary over a wide range, depending on many factors. Walking speeds have been found to decline with age. Studies have also shown that male walking speeds are typically faster than female walking speeds. Other factors influencing a pedestrian's walking speed include the following:

- Time of day;
- Weather and temperature;
- Pedestrian traffic composition, including wheelchair users;
- Trip purpose; and
- Reaction to surrounding environment.

Free-flow walking speeds have been shown to range from 145 ft/min (45 m/min) to 470 ft/min (145 m/min). On this basis, speeds below 145 ft/min (45 m/min) would constitute restricted, shuffling locomotion, and speeds greater than 470 ft/min (145 m/min) would be considered as running. A pedestrian walking speed typically used for design is 250 ft/min (75 m/min), which is approximately 3.0 mi/h or 4.5 km/h.

Walking speeds of elderly persons may be less. *TCRP Report 112/NCHRP Report 562* recommends a minimum walking speed of 3.5 ft/s (210 ft/min or 65 m/min) for timing crosswalk signals (*18*). This speed may have applications elsewhere when planning for the elderly in transit facilities.

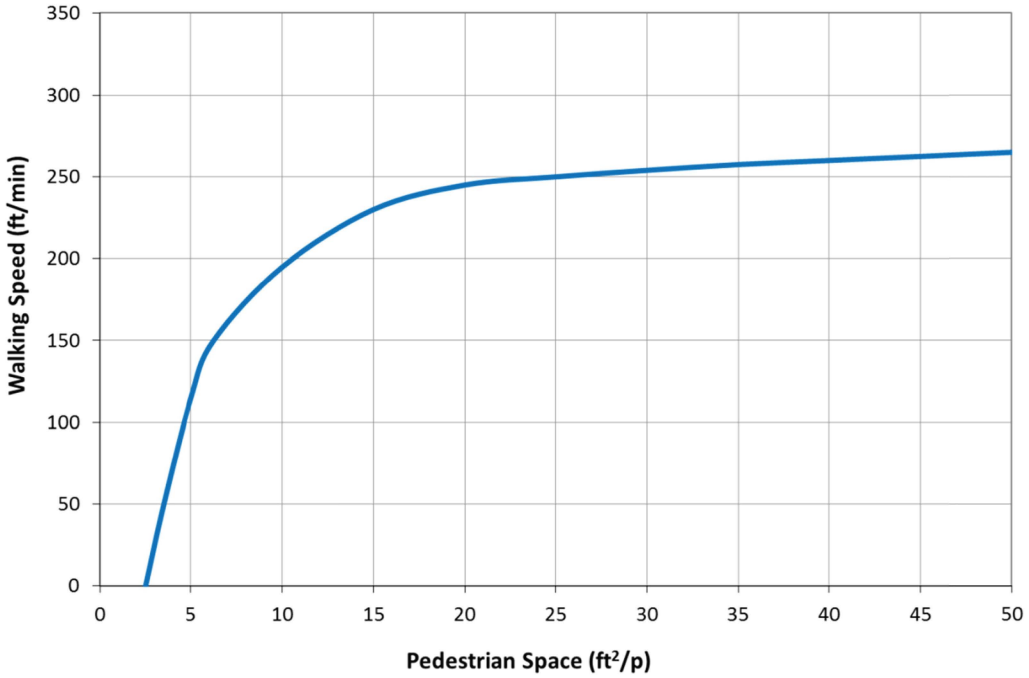
Density

Perhaps the most significant factor influencing pedestrian walking speed is density. Normal walking requires sufficient space for unrestricted pacing, sensory recognition, and reaction to potential obstacles. Increasing density reduces the available space for walking and it increases conflicts between pedestrians and therefore reduces walking speeds. This is an even greater concern for people who use mobility aids such as crutches, canes, and wheelchairs.

Density is the most significant factor influencing pedestrian walking speed.

Exhibit 10-10 shows the relationship between walking speeds and average pedestrian space (the inverse of density). Observing this exhibit, pedestrian speeds are free-flow up to an average pedestrian space of 25 ft² (2.3 m²) per person. For average spaces below this value, walking speeds begin to decline rapidly. Walking speeds approach zero, becoming a slow shuffle, at an average pedestrian space of approximately 5 ft² (0.5 m²) per person.

Exhibit 10-10
Pedestrian Speed on Walkways



Source: Fruin (*2*).
Note: A metric version of this exhibit appears in Appendix A.

Effective Walkway Width

The full walkway width will not be used by pedestrians.

The final factor affecting a walkway's capacity is the effective width available. Studies have shown that pedestrians keep as much as an 18-in. (0.5-m) buffer between themselves and adjacent walls, street curbs, platform edges, and other obstructions, such as trash receptacles, sign posts, and so forth. In practice, the width of the unused buffer depends on the character of the wall or obstruction, the overall width of the available walkway, and on the level of pedestrian congestion. In general, 18 in. (0.5 m) should be deducted next to platform edges and 12 in. (0.3 m) should be deducted next to walls and other obstructions more than 3 ft (1 m) tall. Obstructions 3 ft (1 m) tall or less may have a smaller buffer of 6 to 12 in. (0.2 to 0.3 m).

Exhibit 10-11 shows the relationship between pedestrian flow per unit of effective walkway width and average pedestrian space. Curves are shown for one-directional, bi-directional, and multi-directional (cross-flow) pedestrian traffic. As this exhibit shows, there is a relatively small range in variation between the three curves. This finding suggests that reverse and cross-flow traffic do not significantly reduce pedestrian flow rates, however there may be specific instances where this is not the case, for example, constrained or narrow walkway areas, cross passages where sightlines prevent

converging pedestrians from viewing one another, and areas where wayfinding decision making (or other activities that distract pedestrians) may occur.

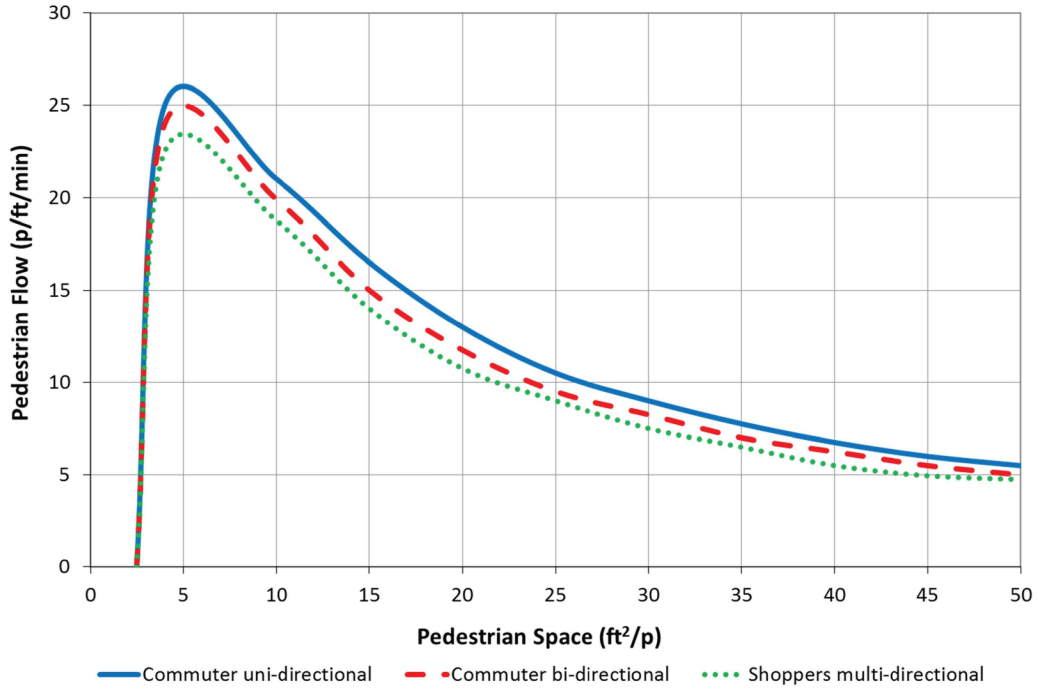


Exhibit 10-11
Pedestrian Flow on Walkways by Unit Width and Space

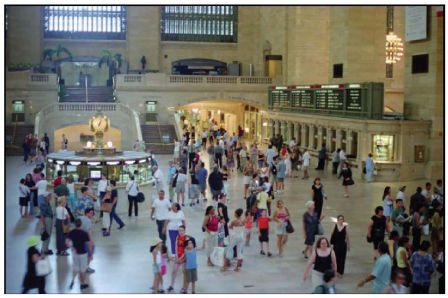
Source: Fruin (*2*).
Note: A metric version of this exhibit appears in Appendix A.

As shown in Exhibit 10-11, the maximum average peak-flow rates (26.2, 24.7, and 23.3 p/ft/min, or 86.0, 81.0, and 76.4 p/m/min, for one-directional, bi-directional, and multi-directional flow, respectively) occur at an average occupancy of 5 ft² (0.5 m²) per person. While this represents the maximum possible throughput, it represents a condition of extreme congestion, does not reflect the needs of mobility impaired persons, and creates a potentially unsafe condition. Therefore, it should not be used as a basis for design. The LOS concept of designing to a desired level of pedestrian comfort is recommended instead.

Multi-activity Passenger Circulation Areas

Some areas of transit stations include a variety of pedestrian activities within the same general space. People may be walking through, standing in line to buy tickets, waiting to meet someone, and shopping within the same space. Portions of these spaces may also be of little use to pedestrians, such as a corner beyond the major flow of pedestrians or concentrations of other activities.

Exhibit 10-12
Examples of Multiple Pedestrian Activities Within a Transit Station



(a) Grand Central Terminal (New York)



(b) Victoria Station (London)

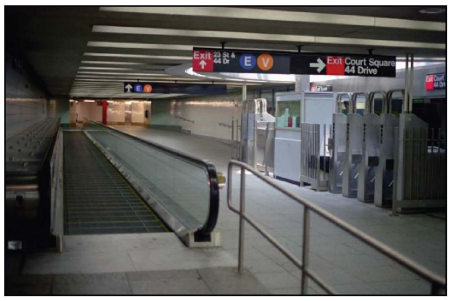
Time–space analysis is used to study complex passenger circulation patterns involving multiple activities.

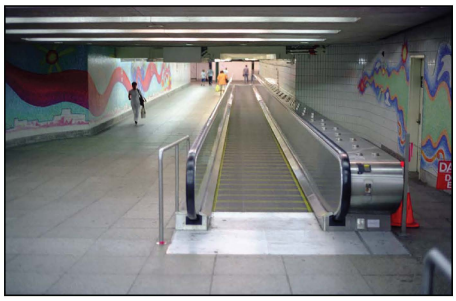
In such cases, either the pedestrian time–space analysis method is applied or pedestrian flows are simulated using pedestrian microsimulation software (*20*). Time–space analysis incorporates the space per person thresholds embodied in the LOS approach and factors them by the time spent engaging in a specific activity within a given space.

Moving Walkways

Moving walkways (Exhibit 10-13) are very common in larger airports, but have been applied less frequently in transit station contexts. Moving walkways are normally installed where large numbers of pedestrians traverse medium and longer distances, from approximately 100 to 1,000 ft (30 to 300 m), such as when connecting two relatively distant platforms at a transfer station. Individual moving walkways can be constructed in varying lengths, but they are rarely more than 400 ft (120 m) in length, with longer distances being covered by a series of moving walkways with a circulation space between each successive walkway.

Exhibit 10-13
Moving Walkway Examples (New York)





Moving walkways normally operate at a speed of 100 ft/min (30 m/min) but some operate at up to 160 ft/min (50 m/min). Thus, most moving walkways operate at less than walking speed. Moving walkways that accelerate pedestrians to a faster speed have been developed but have had limited success due to user difficulty in maintaining balance on entering and exiting and service reliability. A pair of moving walkways that accelerate in the middle of the run are operating at Toronto Pearson International Airport.

Design Factors

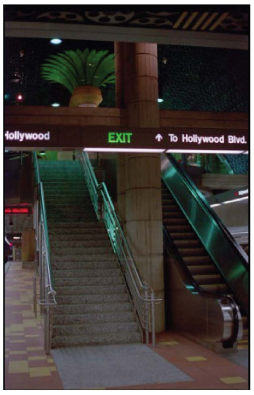
When planning moving walkways, the following factors should be considered:

- The pedestrian volumes moving in each direction. For longer multi-unit moving walkway systems, the volumes may differ in various segments as pedestrians access intermediate destinations.
- Adequate space, measured in corridor width, for moving walkways and a parallel walkway (a) to carry those who cannot or do not wish to use the moving walkway and (b) to serve as an alternate route when a walkway is undergoing maintenance.
- The ongoing cost of operating and maintaining the moving walkway.

VERTICAL CIRCULATION

Stairways

In stations where the platform area is grade separated from the rest of the station and the adjacent outside area, stairways traditionally have been applied as the primary vertical pedestrian movement system. Exhibit 10-14 shows typical treatments.



(a) Los Angeles



(b) Portland

Exhibit 10-14
Stairway Examples

The capacity of a stairway is largely affected by the stairway width. Unlike walking on a level surface, people tend to walk in lines or lanes when traversing stairs. The stairway width determines both the number of distinct lines of people who can traverse the stair and the side-to-side spacing between people. This spacing, in turn, affects pedestrians' ability to pass slower-moving pedestrians and the level of interference between adjacent lines of people. The consequence is that meaningful increases in capacity are not directly proportional to the width, but occur in increments of about 30 in. (0.75 m).

A stairway's capacity is largely affected by its width.

Unlike on walkways, a minor pedestrian flow in the opposing direction on a stairway can result in a capacity reduction disproportionate to the magnitude of the reverse flow. As a result, a small reverse flow should generally be assumed to occupy one pedestrian lane or 30 in. (0.75 m) of the stair's width. For a stair 60 in. (1.5 m) wide, a small reverse flow could consume half its capacity.

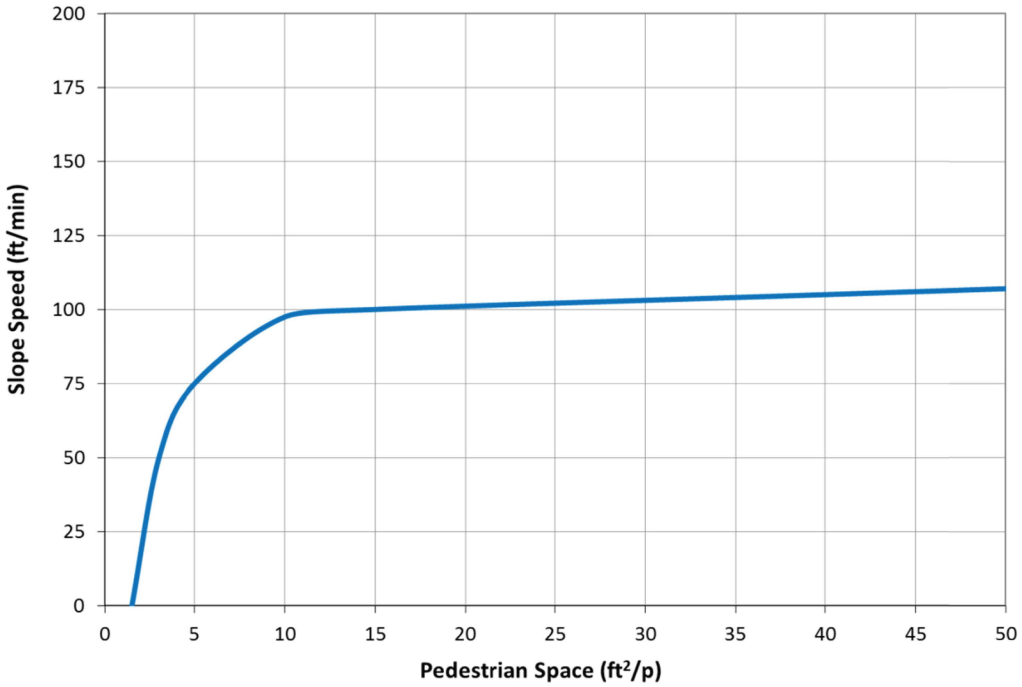
Critical passenger flows on stairways occur in the ascending direction.

Because pedestrians are required to exert a higher amount of energy to ascend stairs as compared with descending stairs, lower flow rates typically occur in the ascending direction. For this reason, when stairs serve both directions simultaneously or when the same stair will be used primarily in the up direction during some time periods and primarily in the down direction during other time periods, the lower ascending flow rate should be used for analysis and design.

Ascending speeds on stairs have been shown to range from 41 ft/min (12 m/min) to 68 ft/min (21 m/min), measured in the vertical dimension (as opposed to measuring along the incline). Descending speeds on stairs have been shown to range from 56 ft/min (17 m/min) to 101 ft/min (31 m/min), measured in the vertical dimension. Ascending speeds are also slower on stairs with greater rises because pedestrians slow as they become more tired toward the top. For general planning and design purposes, average speeds of 50 ft/min (15 m/min) in the up direction and 60 ft/min (18 m/min) in the down direction, measured in the vertical dimension, are considered reasonable. The angle of a stair's incline affects pedestrian comfort, safety, and speeds. While less-steep stairs decrease pedestrian speed measured on the vertical dimension, they increase speeds measured along the horizontal and diagonal dimensions and improve passenger comfort and safety. The vertical dimension is the overall height or rise of a stair; the horizontal dimension is the length or run of the stair; and the diagonal dimension is the length of the stair measured along the incline.

Exhibit 10-15 illustrates the relationship between ascending speeds and pedestrian space. This exhibit reveals that normal ascending speeds on stairs are approached at an average pedestrian space of approximately 10 ft^2/p (0.9 m^2/p). Above approximately 20 ft^2/p (1.9 m^2/p), faster walking pedestrians are able to approach their natural unconstrained stair climbing speed and pass slower-moving people.

Exhibit 10-15
Pedestrian Ascent Speed on Stairs



Source: Fruin (*2*).
Note: A metric version of this exhibit appears in Appendix A.

Exhibit 10-16 illustrates the relationship between flow rate on stairs in the ascending direction and pedestrians' space. As observed in this exhibit, the maximum ascending flow rate occurs at a pedestrian space of approximately 3 ft²/p (0.3 m²/p). For this lower pedestrian space, ascending speeds are at the lower limit of the normal range. In this situation, forward progress is determined by the slowest moving pedestrian. Although the maximum flow rate represents the capacity of the stairway, it should not be used as a design objective (except perhaps for emergency situations). At capacity, ascending speeds are restricted and there is a high probability of intermittent stoppages and queuing.

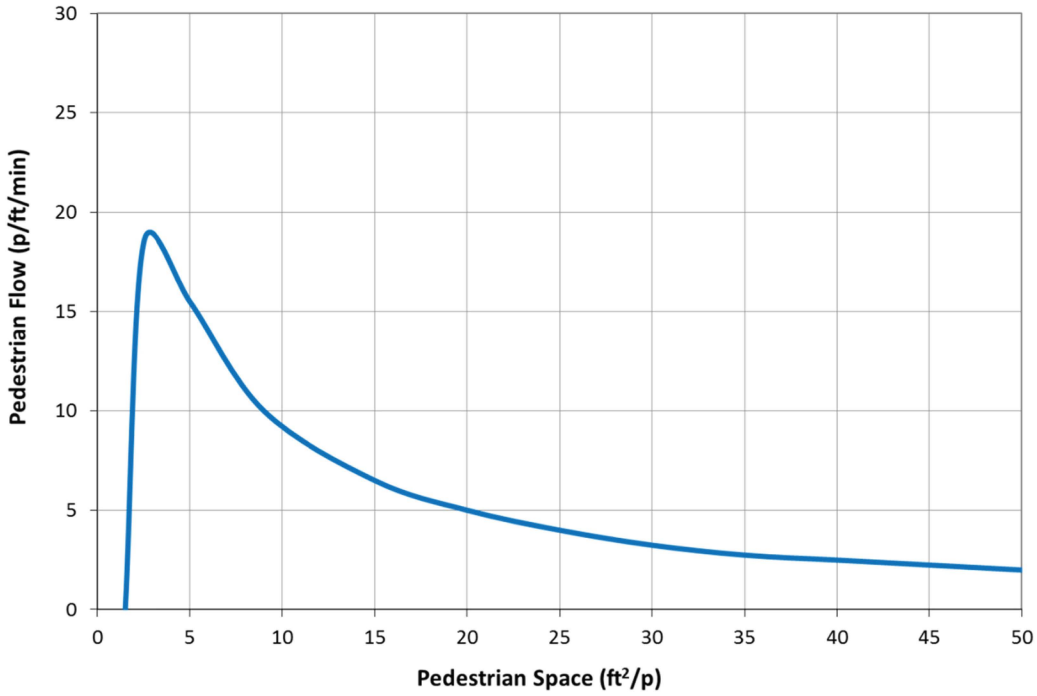


Exhibit 10-16
Pedestrian Flow Volumes on Stairs

Source: Fruin (*2*).

Note: A metric version of this exhibit appears in Appendix A.

Passenger queuing can occur at the destination end of stairways, if people are forced to converge on too constricted a space. This can be a serious design deficiency in certain terminal facilities, with potential liability exposure. Because this can cause a backup on the stairs, it is even more critical than ensuring that adequate space is provided at entry points.

Escalators

Design Factors

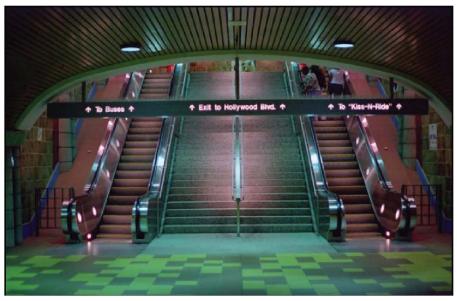
Escalators (Exhibit 10-17) have been installed in many transit stations where there are grade separations between the platforms, other areas of the station, or the outside areas. Typically, escalators are used to supplement stairways and, in many cases, the two facilities are located adjacent to one another. When possible, co-location of stairs, escalators, and one end of an elevator is important for pedestrians with visual

impairments or service animals, as these pedestrians do not use escalators, and guide dogs are trained to avoid escalators.

Exhibit 10-17
Escalator Configuration Examples



(a) Denver



(b) Los Angeles

The capacity of an escalator is dependent upon the entry width and operating speed. In the United States and most other countries, the normal angle of incline of escalators is 30 degrees, and the stair width is either 24 or 40 in. (0.6 or 1.1 m) at the tread. Operating speed is typically 90 ft/min (27.4 m/min), but a higher speed of 120 ft/min (36.6 m/min) is occasionally used when allowed by code and insurance underwriters. These operating speeds are within the average range of stair-climbing speeds.

Studies have shown that increasing the speed of an escalator from 90 to 120 ft/min (27.4 to 36.6 m/min) can increase the capacity by as much as 12%, as people enter the escalator more rapidly. Another interesting finding is that the practice of walking on a moving escalator does not significantly increase escalator capacity, although it does increase a person's overall travel speed. An escalator's capacity is established at its entrance and a moving pedestrian must occupy two steps at a time, thereby reducing the standing capacity of the escalator (*2*).

The size of the queuing area provided at the exiting end of an escalator is an important consideration.

As with stairways, both ends of an escalator require some queuing area if passenger demand exceeds the capacity of the facility. A clear area at the end of an escalator is especially important, as passengers are unable to queue on a moving escalator and will be pushed into the area at the end. The area at the end of an escalator should be wider than the escalator itself to allow people to quickly pass anyone who has stopped at the end of the escalator, and this area should be free of any queues, such as for another escalator, fare gate, ticket machine, vending machine, or automated teller machine. This clear area should generally be at least 20 ft (6 m) in length.

Ramps, Lifts, and Elevators

Ramps, lifts, or elevators are required in new or modified grade-separated facilities to meet ADA requirements.

Ramps, lifts, or elevators are required in all new transit or modified transit stations in the United States to meet ADA requirements when level changes are required to access or move within a station. These requirements are defined in the ADA Accessibility Guidelines (*3*).

Ramps

Ramps may be provided primarily to serve people with disabilities, but are also useful to passengers with baby carriages, wheeled luggage, or heavy packages. Some persons with disabilities who can negotiate stairs will prefer a ramp and will use one if it is available and convenient. Ramps may also be designed for general passenger use in place of stairs or steps. While ramps generally should not have a slope greater than 1:12

(8.3%), an even more gradual slope (1:20 to 1:16, or 5% to 6.25%) is preferred wherever feasible. The ADA requires level landings at the ends of each ramp, and at the end of each ramp run. In addition, the ADA limits the lengths of individual ramp runs, and the maximum rise of each run.

Used as an alternative to elevators or lifts, ramps have the advantage that they require little maintenance, have no operating cost, and are available to a broader spectrum of passengers who may choose them.

Lifts

Open lifts are sometimes used in stations to move passengers using mobility aids between levels a few feet apart, in locations where a ramp is not feasible.

Elevators

Elevators may be provided at one end of a platform or in the center. Separate elevators may be needed between the street and the concourse (mezzanine), and between the concourse and the platforms. Side platform stations generally require at least two elevators, whereas a center platform station may only require one. In the case of especially deep stations, as in New York City (e.g., 168th, 181st, and 191st Streets), Washington, DC (Forest Glen), and Portland (Washington Park), elevators are the sole means of passenger access to and from stations, not including emergency stairs.

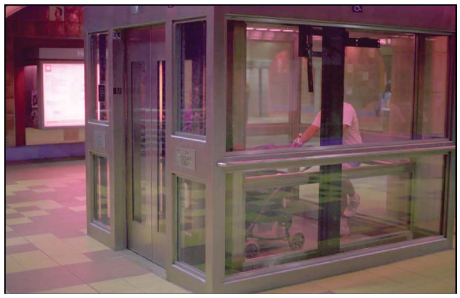
Ongoing elevator maintenance is important for keeping stations consistently ADA accessible.

Good, ongoing elevator maintenance is important for maintaining accessibility for mobility-impaired passengers at transit stations. As a cost-saving measure, most transit stations provide only one elevator per platform, or from the concourse level to the street. However, when any of these elevators is out of service, the station is effectively inaccessible to mobility-impaired passengers. Although these passengers can be served during these times by directing them to alternate stations and providing them with paratransit bus service to their destination, it is much less convenient for these passengers and serves to reduce the accessibility and convenience of the transit system as a whole to passengers with disabilities.

Exhibit 10-18 shows typical elevator applications in a transit station. Traffic flow on elevators differs from other vertical pedestrian movers. As opposed to escalators and stairs, which provide constant service, elevators provide on-demand service. Because of its characteristics, determining the capacity of an elevator is similar to determining the capacity of a transit vehicle.



(a) Station access (Portland)



(b) Station circulation (Los Angeles)

Exhibit 10-18
Elevator Application Examples

PLATFORMS AND WAITING AREAS

Bus Stop and Station Platforms

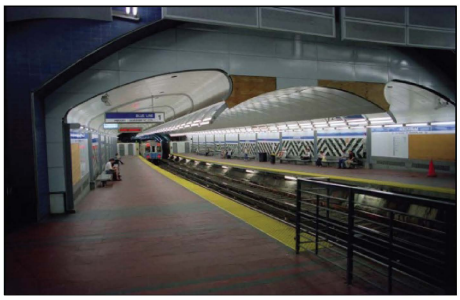
Transit platforms function as waiting and queuing areas for passengers waiting for a transit vehicle to arrive, and as circulation areas for both departing and arriving passengers. The effective platform area required is based on maintaining a minimum LOS for queuing and circulation. It is important to note that transit platforms have critical passenger holding capacities, which, if exceeded, could result in passengers being pushed onto tracks or roadways.

It is important to consider the characteristics of passengers and provide for passengers who may require additional space. Exhibit 10-19 illustrates typical side and center platform configurations at stations. Passengers do not spread out evenly on platforms, however, so that a platform that has enough space overall may experience congestion in specific areas, especially shortly after a transit vehicle arrives. These patterns are best analyzed through the use of pedestrian microsimulation software. The placement and direction of stairs, escalators, and other means of accessing platforms can have a significant effect on the distribution of passengers on a platform and can also enhance or impede exit from the platform. Thus platform loading is a key design consideration when planning these elements.

Exhibit 10-19
Transit Station Platform Configurations



(a) Center platform (Philadelphia)



(b) Side platform (Boston)

ADA considerations for station platforms.

The ADA affects the design of various platform elements, including platform edge treatments. For example, stairs with an open sloping underside must be protected so that people with a visibility impairment will encounter a barrier before potentially striking their head against the sloped bottom of the stairway. ADA does not directly affect the overall area or width required for a platform, but an accessible route at least 36 in. (915 mm) wide must be maintained along the platform. When the accessible route is next to the platform edge, the 24-in. (610-mm) platform edge treatment area is not included, so the total clear width along a platform edge must be 60 in. (1,525 mm).

Shelters, Waiting Rooms, and Seating

Shelters provide protection from rain, wind, and sun.

Shelters are typically used with bus stops or transit stations that are largely unenclosed to provide protection from rain, wind, and sun. In some cases they may also be heated. The design of shelters is influenced both by local climate and the desired level of amenity. For example, in colder, windier climates, shelters may be more enclosed with walls whereas in milder climates they may have only partial walls to act as a wind break. In a bus rapid transit system, station shelters may incorporate the

additional function of providing a fare-controlled area and may encompass a raised platform to provide high-level boarding.

Shelters often have a modular design for cost effectiveness, branding consistency, and to provide flexibility for installing multiple modules at busier stations or single modules at stations with lighter traffic. Transparent sides on shelters improve both real and perceived security, although one or more sides of a shelter may be used for advertising to pay part or all of the cost of the shelters. Another consideration is electrical supply to shelters and integral lighting and information systems.

Waiting rooms are typically associated with larger bus terminals or rail stations and tend to provide a greater degree of climate control than shelters. While shelters may have a very limited number of seats or benches, waiting rooms tend to provide more. Waiting rooms may also contain ticket windows, ticket machines, telephones, and vending machines, and may provide a climate-controlled area for passengers who use those facilities.

Seating may be provided anywhere in a station. Providing seating in different areas, such as on a platform and in a waiting room, offers passengers the opportunity to select seating most convenient to them. Seating is particularly useful for the elderly and when transit service is less frequent, resulting in increased passenger waiting times in a station. When designing seating and determining the desired number of seats, it should be recognized that closely spaced seats may not be used due to discomfort at close interpersonal spacing or partial occupancy by a person sitting in the next seat, even though additional people may wish to sit. Seat perches and lean bars may provide some useful additional comfort for waiting passengers in locations where providing full-size seating is not possible.

4. VEHICLE CIRCULATION AND STORAGE

TRANSIT VEHICLES

Off-Street Bus Stops

Off-street bus stops are typically provided as part of an all-bus transit center or in conjunction with a rail station. For small transit stations, the number of berths (loading areas) is small, with a fairly simple access and layout configuration. For larger terminals, numerous berths and more sophisticated designs are applied.

Determining the Required Number of Bus Berths

The number of bus berths provided at a bus station depends on a variety of factors, including the size and layout of the site; the number of routes passing through the station and their headways; and the number of routes terminating at the station, their headways, their scheduled layover/recovery time, and the type of buses and services (e.g., urban, regional, intercity).

One method for determining the *maximum* required bus berths is as follows (*21*):

- Routes running through the station require two berths to pick up and drop off passengers (one for each direction of the route).
- Routes terminating at the station require one berth to pick up passengers and, potentially, additional layover berths, if it is likely that one or more following buses on a route would arrive prior to the end of a given bus's recovery time.
- The number of berths needed for a route is determined by the route's recovery time at station divided by the route headway, multiplied by a factor of 1.2 to account for early-arriving buses, rounded up. For example, a route with 5-minute headways and a 10-minute recovery at the station would require (10 / 5 × 1.2) = 2.4 berths, rounded up to 3 berths. If the calculation indicates that only one berth is required, layover needs can be met in the berth used for passenger pick-up and no separate layover berth is required.
- When layover berths are required, an additional berth shared by all terminating routes should be provided in a convenient location (from the passenger point-of-view) for dropping off passengers. More than one berth might be needed, depending on bus volumes and arrival patterns.
- Boarding berths should also be located at convenient locations for passengers; layover berths can be situated in more remote portions of the site.
- Headways and recovery time may vary over the day, so the combination that produces the greatest required number of berths should be used in determining the maximum number of berths needed. Consideration should also be given to sizing the station to accommodate future growth (i.e., anticipated route headways in the long term).

This arrangement provides one berth for each route or route direction, which provides a simple-to-understand configuration for passengers, and also works best for accommodating timed transfers. It also provides sufficient layover berths to serve all of the buses that would likely be on the site at the same time. When available space or

construction costs are significant constraints, the number of berths can be reduced by investigating the potential to share berths:

- Routes that would not use the station at the same time (because they operate at different times of day or pass through the station at different times during the hour) could share berths.
- Layover berths needed only to accommodate early buses could potentially be shared, but with an increased risk of the number of buses on site exceeding the number of layover berths provided, if both buses sharing a layover berth arrived early.
- If timed transfers are not used, stops could also operate like larger on-street stops, with multiple loading areas per stop and arriving buses pulling forward to the first available berth.

Berths that are shared between routes must be long enough to serve the longest bus operated on any of the routes sharing the berth. The number of routes sharing a single berth should be kept to a minimum where possible to minimize passenger confusion.

"Intelligent" bus stations have been developed in some European cities (*10*). Buses are assigned a specific berth as they approach within a few minutes of the station and electronic signage at the station informs passengers at which berth their bus will arrive. This arrangement is similar to a hub airport, where a particular gate may serve flights to many different destinations over the course of a day. Although this system does not reduce the total number of berths that are needed for peak conditions, it does offer the potential to provide a higher level of amenities at the most convenient (and therefore most heavily used) berths; a central passenger waiting area is also typically provided.

Bus terminals should be sized to provide ample space for passenger circulation, queuing, and amenities. However, terminals that are larger or more spread out than necessary to serve their functions can increase passenger transfer times and operating costs, and may be less secure.

Bus Berth Designs

Exhibit 10-20 illustrates various berth designs. Four types of bus berths are typically applied: linear, sawtooth, drive-through, and pull-in/back-out. Many larger bus-operating transit agencies have developed design guidance for bus berths specific to their bus fleets. Preferably, desired operating patterns should dictate the type of bus berths used, rather than the berths placing constraints on the operation. A bus terminal may have more than one type of berth to best serve different operating patterns and characteristics.

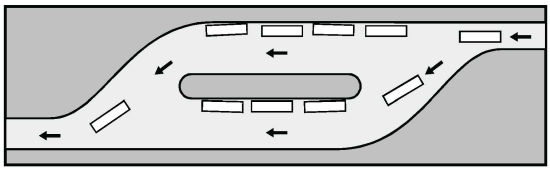
Linear berths can operate in series and have capacity characteristics similar to on-street bus stops. Their main advantage is that they require the least curb space—as long as buses do not need to move in and out of berths independently of each other. If independent bus movement is required, linear berths can actually require more curb space than other types (e.g., sawtooth), as buffer space is needed between each bus stopping position to allow buses to enter and exit each berth.

Sawtooth berths are a popular design, as they permit independent movement into and out of the berth, while retaining the ability to design bus stops around either a central island platform or along the perimeter of the bus roadway. Both of these types of stations designs minimize the need for pedestrian crossings of the bus roadway.

Shallow sawtooth berths laid end to end are increasingly used in transit terminal design.

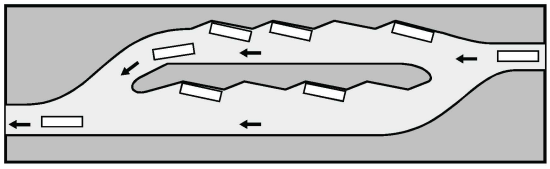
Exhibit 10-20
Bus Berth Designs and Examples

(a) Linear
Linear berths are less efficient than other berth types and are typically used when buses will occupy the berth for a short time (for example, at an on-street bus stop).



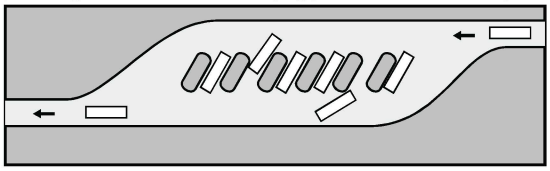


(b) Sawtooth
Sawtooth berths allow independent movements by buses into and out of berths and are commonly used at bus transfer centers.





(c) Drive-Through
Drive-through berths allow bus stops to be located in a compact area, and also can allow all buses to wait with their front destination sign facing the direction passengers will arrive from (e.g., from a station exit).





(d) Pull-In/Back-Out
Pull-in/back-out berths require buses to back out, but allow a number of berths in a compact area. They are typically used when buses will occupy the berth for a long time (for example, at an intercity bus terminal).

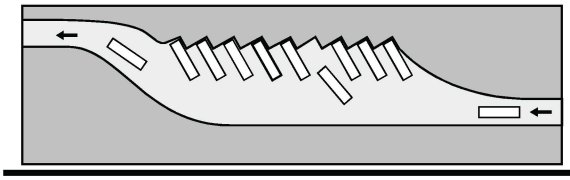




Photo locations:
(a) Newport, RI;
(b) Olympia, WA;
(c) Vail, CO; and
(d) Newark Airport, NJ.

Drive-through berths provide a series of boarding islands placed at a 45° or 90° angle to the flow of bus traffic through the station. They provide a compact bus berth layout, but require passengers to cross the bus roadway to access the islands, which increases potential conflicts between buses and pedestrians.

Pull-in/back-out berths are rarely used in bus transit stations, except in very constrained sites, due to the hazards of backing a bus out with very limited driver visibility (back-up cameras help mitigate this hazard to some degree). They are

sometimes used in intercity bus terminals, where buses occupy berths for long periods of time, and staff may be available to guide bus drivers out of the berths.

The National Transportation Safety Board recommends that transit facility designs incorporating sawtooth berths, or other types of berths that may direct errant buses towards pedestrian-occupied areas, should include provisions for positive separation (such as bollards) between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (*22*).

On-Street Bus Stops

On-street bus stops can be designed using the procedures in Chapter 6, Bus Transit Capacity. Given a known volume of buses to be served, dwell time and clearance time characteristics, and a design level of reliability (i.e., probability that a bus can enter a loading area immediately upon arriving at the stop), the number of berths required to serve the demand can be calculated.

PRIVATE VEHICLES

Park-and-Ride Facilities

Park-and-ride facilities are sized based on estimated demand.

At selected transit stations, park-and-ride facilities for autos are provided (Exhibit 10-21). Generally, park-and-ride facilities are located along the outer portions of a rail line or busway, in the outer portions of central cities, and in the suburbs in metropolitan areas. At many locations, park-and-rides are integrated with bus transfer facilities. Their size can vary from as few as 10 to 20 spaces at minor stations to more than 1,000 spaces at major stations. Most park-and-ride facilities are surface lots, with pedestrian connections to the transit station. Due to their added cost, parking structures are used where land is at a premium and a substantial number of parking spaces are required. Some of these facilities contain several thousand spaces and have direct access to freeways.



(a) Cleveland



(b) Houston

Exhibit 10-21
Park-and-Ride Lot Examples

Surface parking lots around transit stations occupy potentially valuable space that could be used for transit-oriented development. Instead, parking for commuters can be integrated with transit-oriented development. One option is to utilize parking structures in place of surface parking to free additional land for mixed-use development. Parking garages can also contain street-level commercial space to better integrate them with surrounding development. Parking, whether structured or surface,

can also be moved 100 to 300 ft (30 to 90 m) from the station if the area between is developed in a pedestrian-friendly manner. In a mixed-use development, the same parking spaces used by commuters during the daytime can also serve residents, shoppers, and diners during the evening and weekend.

The required number of park-and-ride spaces at a transit station typically involves identifying the demand for such parking, and then relating the space demand to the ability to physically provide such a facility within cost constraints. Parking spaces in park-and-ride facilities typically have a low turnover during the day, as most persons parking at transit stations are commuters who are gone most of the day. In larger urban areas, the regional transportation model will have a mode split component which will help identify park-and-ride demand at transit station locations. This information is particularly applicable for new rail line or busway development. Where the regional model does not have the level of sophistication to provide such demand estimates, then park-and-ride demand estimation through user surveys and an assessment of the ridership sheds for different station areas would be appropriate.

The following are illustrative ranges of the number of parking spaces provided per daily boarding passenger at U.S. public transit stations (*23*):

- Commuter rail: 0.4 to 0.6
- Heavy rail: 0.4 to 0.6 typical, range 0.1 to 1.1
- Light rail: 0.2 to 0.3 typical, range 0.1 to 1.2

The wide range of parking spaces per boarding passenger at light rail and heavy rail stations reflects variations in the mix of walking, bicycling, feeder bus, and kiss-and-ride trips at specific stations, along with variations in development densities around each station and planned long-term passenger volumes at a station (*23*).

TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations (*23*) overviews planning, operating, and conceptually designing park-and-ride lots. It also compares the costs of surface and structured parking for various land costs.

Kiss-and-Ride Facilities

Kiss-and-ride facility capacity is governed by space required for passenger pick-ups.

Kiss-and-rides are dedicated areas at transit stations where transit patrons can be dropped off and picked up by another person in a private vehicle (Exhibit 10-22). Short-term parking is based on the need to serve vehicles waiting to pick up transit riders, as the drop-off requires no parking maneuver (although curb space is needed to handle the drop-off). Parking times for vehicles waiting to pick up passengers averages 7–8 min per vehicle (*23*). As with park-and-ride facilities, the sizing of kiss-and-ride facilities is reflective of the demand and physical constraints of the site.



(a) Denver



(b) Boston



(c) Toronto

Exhibit 10-22
Kiss-and-Ride Examples

Bicycle Access and Parking

Bicycle access can constitute a significant share of the boarding passengers at transit stations: for example, it provided more than 6% of the access mode share at five BART rail stations in 2008 (with a high of 11% at Ashby Station). Many of the factors that encourage bicycling as a transit access mode—for example, bicycle facility quality in the station catchment area, topography, weather, traffic volumes and speeds, and the local bicycling culture—are outside the control of transit agencies; however, the provision of high-quality secure bicycle storage facilities at stations does influence the use of bicycles as an access mode (*23*).

Bicycle storage may be provided at transit stations where demand exists and space allows. Bicycle racks provide a simple, relatively low-cost approach and can hold a large number of bicycles in a relatively small space, but the bicycles are subject to potential damage and theft. Enclosed bicycle lockers and cages provide added protection from theft and from weather, but are more costly and require more space. The demand for bicycle spaces will vary greatly by station and may be best assessed by observation and test provision of facilities. Exhibit 10-23 illustrates different types of bicycle parking options, while Exhibit 10-24 presents their pros and cons.

When bicycles are allowed on board transit vehicles, and elevation changes are required to travel between transit vehicles and station entrances, elevators and ramps are options for facilitating bicycle movement. Stair channels that allow bicyclists to roll their bicycle up and down stairs may also be an option, but their design also needs to accommodate ADA requirements for stairways. At the time of writing, no U.S. standard existed for stair channel design. The Chicago Transit Authority and the Bay Area Rapid Transit District were among the transit agencies that had installed channels at selected stations (*24*).

Exhibit 10-23
Bicycle Parking Examples



(a) Bicycle racks (Clearwater, FL)



(b) Bicycle lockers (San Jose)



(c) Storage cage (Fredericia, Denmark)



(d) Bike-share station (Minneapolis)

Exhibit 10-24
Summary of Secure Bike Storage Options

	Bike Stations	Bike Lockers: Subscription	Bike Lockers: Shared System	Self-Service Bike Cages
Description	Provides valet attended parking. Other services (e.g., lockers, changing rooms, showers, bicycle repair) optional.	Metal or plastic crates for storing bicycles. Self-serve.	Metal or plastic crates for storing bicycles. Self-serve.	Bicycle racks behind a locked door. Free-standing cages, or fenced-in room.
Method of access	Electronic key, must purchase membership.	Subscribers assigned a specific locker.	Electronic key accesses network of lockers on first-come, first-served basis.	Electronic or other entry through door for subscribers.
Typical fees	Monthly or annual subscription.	Deposit and monthly or annual fee.	Fees charged by use (several cents per hour).	Monthly or annual subscription.
Benefits	High level of service and security.	Users guaranteed a spot. More secure than racks.	Higher utilization than subscription lockers. Users pay only for what they use. More secure than racks.	Lower operating costs than attended parking. More secure than open racks. High potential utilization.
Cons	High capital and operating costs. Additional agency-owned infrastructure.	Potential for patrons to store items other than bicycles. Subscription waitlists common. Low utilization.	Potential for patrons to store items other than bicycles. Electronic payment system increases operating costs.	Additional agency-owned infrastructure. Lower security and service compared to attended parking.

Source: *TCRP Report 153* (*23*).

5. STATION ELEMENTS AND THEIR CAPACITIES

INTRODUCTION

This section provides computational methods for sizing the basic elements that might be found in a transit station, working from the outside of the station inward to the transit platform, following the same pattern used in Section 3.

Terms used in this chapter for evaluating pedestrian circulation are defined as follows:

- *Pedestrian capacity*: the maximum number of people who can occupy or pass through a pedestrian facility or element, expressed as persons per unit of area per minute or as persons per unit of width per minute. Both a maximum "absolute" capacity reflecting the greatest possible number of persons who can pass through and a "design" capacity representing the maximum *desirable* number of pedestrians are applied in appropriate ways. Higher "theoretical" capacities are sometimes identified (e.g., for escalators and moving walkways), but are not based on practical experience and are not generally applicable in analysis or design.
- *Pedestrian speed*: average pedestrian walking speed, generally expressed in units of feet or meters per minute or per second. In pedestrian simulation modeling, a range of pedestrian speeds may be used in place of an average speed, better representing the variability in pedestrian activity.
- *Pedestrian flow rate*: number of pedestrians passing a point per unit of time, expressed as persons per minute or other time period; "point" refers to a line across the width of a walkway, stairway, or doorway, or through a pedestrian element such as an escalator or fare control gate.
- *Pedestrian flow per unit width*: average flow of pedestrians per unit of effective walkway width, expressed as persons per inch, foot, or meter of width per minute.
- *Pedestrian density*: average number of persons per unit of area within a walkway or queuing area, expressed as persons per square foot or meter.
- *Pedestrian space per person*: average area available to each pedestrian in a walkway or queuing area, expressed in terms of square feet or square meters per person; this is the inverse of density. The space normally required by people varies according to the activity they are engaged in and increases with walking speed. It is important to consider the type and characteristics of the pedestrians. For example, the area required by a person using a wheelchair or transporting luggage or packages is greater than for a person standing without items.
- *Pedestrian time-space*: the space normally required by pedestrians for various activities (walking across a space, queuing, buying a ticket, shopping, etc.) multiplied by the time spent doing the activity within a specific area.
- *Effective width or area*: the portion of a walkway's or stairway's width or the area of a space that is normally used by pedestrians. Areas occupied by physical obstructions and buffer areas adjacent to open platform edges, walls, and obstructions are excluded from effective width or area.

STATION ACCESS

Doorways

Doorway Level of Service

The LOS criterion selected to evaluate doorways (Exhibit 10-25) should be the same as that used for evaluating walkways. The objective is to maintain a desirable average pedestrian flow rate (or walking speed) throughout the walkway system. Consideration should be made of pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids.

Exhibit 10-25
Doorway LOS

LOS	Pedestrian Space (ft^2/p)	Expected Flows and Speeds: Avg. Speed, *S* (ft/min)	Flow per Unit Width, *v* (p/ft/min)	*v/c*
A	≥ 35	260	0–7	0.0–0.3
B	25–35	250	7–10	0.3–0.4
C	15–25	240	10–15	0.4–0.6
D	10–15	225	15–20	0.6–0.8
E	5–10	150	20–25	0.8–1.0
F	< 5	< 150	*Variable*	*Variable*

LOS	Pedestrian Space (m^2/p)	Expected Flows and Speeds: Avg. Speed, *S* (m/min)	Flow per Unit Width, *v* (p/m/min)	*v/c*
A	≥ 3.3	79	0–23	0.0–0.3
B	2.3–3.3	76	23–33	0.3–0.4
C	1.4–2.3	73	33–49	0.4–0.6
D	0.9–1.4	69	49–66	0.6–0.8
E	0.5–0.9	46	66–82	0.8–1.0
F	< 0.5	< 46	*Variable*	*Variable*

Source: Fruin (*2*).
Note: *v/c* = volume-to-capacity ratio.

Doorway Capacity

The capacity of a doorway will be based solely on the width of the doorway if it is normally open, but will be reduced if the door is normally closed so that pedestrians have to open it. The capacity of a normally closed door is thus further affected by the difficulty of opening the door, although this effect is reduced if a steady flow of pedestrians keeps the door open for extended periods.

Exhibit 10-26 summarizes observed average headways for different types of doorways. Although it is recommended that headways be recorded at doorways similar in design and operation to the one under investigation, the values in Exhibit 10-26 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free swinging	1.0-1.5	40-60
Revolving, per direction	1.7-2.4	25-35

Source: Fruin (*2*).

Note: Values assume each doorway serves one pedestrian lane.

Exhibit 10-26
Observed Average Doorway Headway and Capacity

Determining the Required Number of Doorways

The following is a list of steps recommended for determining the required number of doorways:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 10-25.
2. Choose an analysis period appropriate to the location of 15 min or less.
3. Estimate the pedestrian demand during the analysis period.
4. Compute the design pedestrian flow (persons per minute) by dividing the demand by the number of minutes.
5. Compute the required width of the doorway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Compute the number of doorways required by dividing the required entrance width by the width of one doorway (always round up).
7. Determine whether the design pedestrian flow exceeds the entrance capacity by following the procedures below.

Determining Entrance Capacity

As discussed above, the capacity of a doorway is based on the width of the doorway and the number of people who can pass through per minute. The following steps may be used to compute the capacity for a given number of entrances:

1. Determine the number of pedestrians who can pass through in 1 minute. Since doorways may display different characteristics, this should be done through field observations at the doorway or one of similar configuration. If field observations are not possible, the lower volume value from Exhibit 10-26 may be used.
2. Compute total entrance capacity (persons per minute) by multiplying the equivalent pedestrian volume by the number of doorways.
3. Adjustments should be made as appropriate to reflect special pedestrian characteristics.
4. Compute hourly pedestrian capacity by multiplying the total entrance capacity by 60.

Emergency Evacuation Capacity

For emergency evacuation purposes, the 2010 edition of NFPA 130 (*1*) requires a minimum doorway or gate width of 36 in. (910 mm). The evacuation capacity of single-leaf doors or gates is 60 p/min. The evacuation capacity of bi-parting doors and gates is based on width: 2.08 p/in./min or 0.0809 p/mm/min. Except where the fare collection

equipment provides unobstructed egress during an emergency, gates must provide at least half of the exit capacity.

Fare Purchase

Ticket Vending Machine Service Times

Because of the range of ticket vending machines (TVMs) in use, and because fare policies are unique to each agency, it is difficult to provide standard service times for TVMs. It is recommended that service times be recorded at machines similar in design to the type under investigation. Fare payment technology continues to evolve and innovations such as automatic recharging of smart card balances and fare payment via mobile telephone will make it less necessary for riders to use TVMs in the future.

Determining the Required Number of Ticket Vending Machines

TCRP Report 80: A Toolkit for Self-Service Barrier-Free Fare Collection (*25*) identifies two potential methods for determining the number of TVMs required at a station:

1. Install sufficient TVMs so that peak-period queues do not exceed "tolerable" levels, except during periods of unusually high demand.
2. Install sufficient TVMs to meet off-peak demand, and supplement them with on-site fare sales during peak times.

Even when only one machine is needed to serve peak demand, a second machine may be needed as an alternate if one machine is out of service; otherwise, the agency will need to develop a policy for accommodating passengers not able to pay their fares when the single machine is out of service.

A simple process for determining the required number of TVMs at a station or entrance is given by Equation 10-1 (*25*):

Equation 10-1

$$N_{TVM} = \frac{P_{arr} p_t}{\left(\frac{3{,}600}{t_t}\right)}$$

where

N_{TVM} = number of required TVMs (round up),
P_{arr} = design number of arriving passengers at a station or entrance (p/h),
p_t = proportion of arriving passengers purchasing a ticket,
3,600 = number of seconds in an hour (s/h), and
t_t = average transaction time (s/p).

The number of TVMs calculated by Equation 10-1 provides sufficient capacity to meet demand over the course of an hour, but it does not prevent queuing from occurring within the hour, due to variations in passenger arrival patterns and individual transaction times. Therefore, an additional queuing analysis may be desirable to determine the probability that an arriving passenger would experience a waiting time exceeding a desired maximum value.

Ticket Validators

Where a proof-of-payment fare system is utilized, ticket validators may be used to validate or cancel a ticket with a time stamp to indicate that the ticket has been used and is valid for travel during a specific time period. Ticket validators are placed both for convenience and clarity to travelers and in a position that is consistent with local policy on where tickets must be validated (i.e., the extent of fare-paid areas). When validation is required before boarding a vehicle, validators are placed on station platforms or boarding areas. Validators may also be placed on vehicles if validation is allowed just after boarding, but this also introduces the possibility that some passengers may validate only when they see an inspector approaching on the vehicle. The number and placement of validators should be sufficient to serve boarding passengers without unduly diverting passengers from their routes to the transit vehicle or to cause unnecessary clustering to reach a validator.

Fare Control

Faregate Capacity

Different fare media and reader systems are in use including tickets that are transported through a reader and both contact and contactless cards. Different processing speeds may be found within each of these categories depending on the mechanical characteristics of the gate and the technologies applied in each system. Generally, however, a well-functioning contactless system tends to be faster than those requiring contact, and contact systems are generally faster than systems that transport tickets. Determining actual processing speeds of a particular fare gate system requires measurement under real-world conditions.

For reference, Exhibit 10-27 summarizes observed average headways for different types of faregates. However, it is recommended that, where possible, headways be observed at faregates that are of a similar design and operation to those under investigation. Observations should be made when a faregate is operating at maximum capacity, as evidenced by a queue at the entry to the gate.

Exhibit 10-27
Observed Average Faregate Headways and Capacities

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free admission (barrier only)	1.0–1.5	40–60
Ticket collection by staff	1.7–2.4	25–35
Single-slot coin- or token-operated	1.2–2.4	25–50
Double-slot coin-operated	2.5–4.0	15–25
BART (transported magstripe ticket, low bi-leaf gate)	2.3–2.9	21–26
London (transported magstripe ticket, high bi-leaf gate)	2.4	25
New York (swiped magstripe ticket, turnstile)	2.6–2.9	21–23
London (smart card, high bi-leaf gate)	2.4	25
Exit gate, 3.0 ft (0.9 m) wide	0.8	75
Exit gate, 4.0 ft (1.2 m) wide	0.6	100
Exit gate, 5.0 ft (1.5 m) wide	0.5	125

Sources: Fruin (*2*), TCQSM 2nd Edition (*26*), Weinstein (*27*), Weinstein et al. (*28*).

Magstripe and smart card readers can theoretically process substantially more passengers per minute than the values suggested by Exhibit 10-27. For example, in a controlled test of the New York subway's faregates using clean card readers and trained staff, between 38 and 53 p/min could be processed, depending on the protocol used for using the faregate (e.g., looking at the faregate's display or not). Reasons that the higher flow rates could not be achieved in actual operation include: (*a*) passengers hesitating briefly to avoid hitting a locked turnstile, (*b*) passengers hesitating to make sure the faregate was ready to accept their ticket, (*c*) misswiping a farecard, (*d*) dirty card reader contacts, and (*e*) passengers carrying items, such as newspapers or small bags (*28*).

Determining the Required Number of Faregates

The procedure to determine the required number of faregates is based on determining the capacity of individual faregates in either direction (entering and existing) and providing enough capacity to handle peak-period conditions and allow for some growth. Special provisions may be made for periodic high volumes such as after a major public event. Consideration should be given to pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids. The possibility of one or more gates being unavailable due to malfunction or maintenance should be considered. The following steps are recommended for determining the required number of faregates:

1. Choose an analysis period appropriate to the location of 15 minutes or less.
2. Estimate the pedestrian demand during the analysis period.
3. Compute the design pedestrian flow (passengers per minute) by dividing the demand by the number of minutes.
4. Compute the number of gates, turnstiles, or combination required by dividing the passenger flow by the capacity of individual units, or subtracting the capacity of units if more than one type is to be used (always round up or add one extra unit for each direction of flow). One gate should always be provided for reverse flow, even if the reverse flow is relatively minor.

Emergency Evacuation Capacity

For emergency evacuation purposes, the 2010 edition of NFPA 130 (*1*) sets a capacity of 25 p/min for turnstiles and 50 p/min for gate-type barriers. Electronically operated faregates are required to open to allow unimpeded egress during evacuations. NFPA 130 also sets minimum and maximum dimensions for gate-type faregates.

HORIZONTAL CIRCULATION

Walkways

Principles of Pedestrian Flow

As was illustrated in Section 3, pedestrian speed, flow, and density are interrelated. The relationship between density, speed, and flow for pedestrians is described by the following formula:

Equation 10-2

$$v = S \times D$$

where

v = pedestrian flow per unit width (p/ft/min, p/m/min),
S = pedestrian speed (ft/min, m/min), and
D = pedestrian density (p/ft², p/m²).

The flow variable used in this expression is expressed as a flow per unit of width. An alternative and more useful expression can be developed using the reciprocal of density, or *space*, as follows:

$$v = S/M$$

Equation 10-3

where

v = pedestrian flow per unit width (p/ft/min, p/m/min),
S = pedestrian speed (ft/min, m/min), and
M = pedestrian space (ft²/p, m²/p), adjusted as appropriate for pedestrian characteristics.

Levels of Service for Walkways

Exhibit 10-28 lists the thresholds for pedestrian LOS on walkways in transit facilities. These levels of service are based on average pedestrian space and average flow rate. Average speed and volume-to-capacity ratio are shown as supplementary criteria. Maximum capacity is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS E.

Note that the LOS thresholds shown here differ from those shown in the HCM 2010 (*29*). Thresholds shown in the HCM 2010 are intended primarily for sidewalks and street corners, while those shown here are typically used for transit facilities, whether on-street or off.

LOS thresholds for walkways are not the same as the HCM's thresholds for sidewalks.

Exhibit 10-28
Walkway LOS

LOS	Pedestrian Space (ft²/p)	Expected Flows and Speeds: Avg. Speed, *S* (ft/min)	Flow per Unit Width, *v* (p/ft/min)	*v/c*
A	≥ 35	260	0–7	0.0–0.3
B	25–35	250	7–10	0.3–0.4
C	15–25	240	10–15	0.4–0.6
D	10–15	225	15–20	0.6–0.8
E	5–10	150	20–25	0.8–1.0
F	< 5	< 150	*Variable*	*Variable*

LOS	Pedestrian Space (m²/p)	Expected Flows and Speeds: Avg. Speed, *S* (m/min)	Flow per Unit Width, *v* (p/m/min)	*v/c*
A	≥ 3.3	79	0–23	0.0–0.3
B	2.3–3.3	76	23–33	0.3–0.4
C	1.4–2.3	73	33–49	0.4–0.6
D	0.9–1.4	69	49–66	0.6–0.8
E	0.5–0.9	46	66–82	0.8–1.0
F	< 0.5	< 46	*Variable*	*Variable*

Source: Fruin (*2*).
Note: *v/c* = volume-to-capacity ratio.

Pedestrian Demand

When estimating the pedestrian demand for a particular facility, it is important to consider short peak periods and surges within the peak. For general design purposes, a 15-min peak period is usually recommended. However, because micropeaks (temporary higher volumes) are likely to occur, consequences of these surges within the peak should be considered. Due to the incidence of intensive peaks just after a transit vehicle arrives and discharges passengers, analysis of a shorter time period may be appropriate for walkway segments close to a transit platform. Where headways are very close, the time between trains or buses may define the period of analysis on these segments. Micropeaking may result in increased crowding for a given time period, but the short duration may justify the temporary increase in congestion and short duration queuing.

Determining Required Walkway Width

The procedures to determine the required walkway width for a transit terminal corridor are based on maintaining a desirable pedestrian LOS. Exhibit 10-28 lists the pedestrian LOS thresholds for walkways. These levels of service are based on average pedestrian spaces and average flow rates. It is generally desirable for peak-period pedestrian flows at most transit facilities to operate at LOS C or above. The following steps are recommended for determining the required walkway width:

1. Chose an appropriate analysis period in minutes; this may be the headway or another period but not generally more than 15 min.
2. Based on the desired LOS, choose the maximum pedestrian flow rate (p/ft/min or p/m/min) from Exhibit 10-28.
3. Estimate the pedestrian demand for the walkway during the desired analysis period.
4. Compute the design pedestrian flow (p/min) by dividing the demand by the number of minutes.
5. Compute the required effective width of walkway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Compute the total width of walkway (in feet or meters) by adding 2 to 3 ft (0.6 to 1.0 m), with a 12- to 18-in. (0.3- to 0.5-m) buffer on each side to the effective width of walkway.

Determining Maximum Walkway Capacity

The maximum capacity of a walkway is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS E. Therefore, for a given walkway width, the following steps may be used to compute the maximum capacity:

1. Compute the effective width of walkway (ft or m) by subtracting 3 ft (1 m) or other appropriate buffer zones from the total walkway width.
2. Compute the design pedestrian flow (p/min) by multiplying the effective width of walkway by 25 p/ft/min (82 p/m/min).
3. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

As noted previously, station elements should not be designed for maximum capacity under normal operating conditions, as doing so results in uncomfortably dense

concentrations of pedestrians and constrains the ability of station elements to accommodate growth in passenger volumes.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for platform, corridor, and ramps of 4% slope or less should be used in place of the values presented above. In the 2010 edition, these values were a pedestrian flow rate of 2.08 p/in./min (0.0819 p/mm/min), and a travel speed of 200 ft/min (61 m/min) (*1*). The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

Multi-activity Passenger Circulation Areas

The time-space required for a particular activity is represented by the equation:

$$TS_{req} = \sum P_i \times S_i \times T_i$$ **Equation 10-4**

where

TS_{req} = time-space required (ft²-s, m²-s),

P_i = number of people involved in activity *i* (p),

S_i = space required for activity *i* (ft²/p, m²/p), and

T_i = time required for activity *i* (s).

The total time space requirements of all of the activities are then compared with the time-space available, represented by the formula:

$$TS_{avail} = S_{avail} \times T_{avail}$$ **Equation 10-5**

where

TS_{avail} = time-space available (ft²-s, m²-s),

S_{avail} = space available within the area analyzed (ft², m²), and

T_{avail} = time available as defined for the analysis period (s).

The approach to applying time-space analysis varies depending on the situation being analyzed and the specific issues or options to be addressed. A typical application might involve the following steps:

Steps for applying a time-space analysis.

1. Establish pedestrian origins and destinations within and at the edges of the space analyzed.
2. Assign pedestrian routes through the pedestrian network for each origin-destination pair.
3. Sum the volumes of persons passing through each analysis zone.
4. Identify the walking time within each zone for pedestrians. This may vary depending on their route through each zone.
5. Determine the percentage of people passing through each zone who stop and dwell in that zone for various specific purposes, such as waiting for a train, buying tickets, shopping, etc.
6. Determine the time spent dwelling in each zone for each purpose.

7. Calculate the time-space demand by multiplying the number of persons and the number dwelling by the time for walking through and the dwell time for various activities and by the space used by a person engaged in each activity.
8. Calculate the time-space available by multiplying the usable floor area by the duration of the analysis period.
9. Calculate the demand-supply ratio by dividing time-space demand by time-space available.
10. Apply an LOS based on ranges of demand-supply ratios.

Computer microsimulation programs for pedestrian circulation have developed to a point where they are useful for analysis of both simple and more complex pedestrian environments, and they are replacing spreadsheet-based time-space analysis in many situations. The application of pedestrian microsimulation software is discussed in Section 6.

Moving Walkways

Moving Walkway Capacity

The capacity of a moving walkway is primarily dependent on its width at its entrance, as this determines the number of people who can enter the walkway. The speed of the walkway only affects the capacity to the extent that it affects the spacing of people as they enter. Walking on a moving walkway increases pedestrian travel speed and reduces travel time, but does not affect capacity because it does not affect the rate of entry to the moving walkway. Likewise, systems that accelerate pedestrians to higher speeds do not significantly increase the capacity compared with a standard moving walkway of the same width because the capacity at the entrance is the same as a standard speed unit and governs the capacity.

Manufacturers of moving walkways sometimes state theoretical capacities based on square feet of walkway per minute. These theoretical capacities are generally much higher than practical capacities and should not be used in passenger flow analysis. Studies have shown that the practical capacity of a double-width moving walkway is comparable with the capacity of a double-width escalator of equal width, or approximately 90 p/min or 5,400 p/h.

Evaluation Procedure

In typical application, no more than one moving walkway is provided per direction, with any additional capacity requirements accommodated by an adjacent walkway. The procedures to determine the required queuing area at each end of the walkway are similar to the procedure for escalators, discussed later in this section.

Emergency Evacuation Capacity

The NFPA 130 standard (*1*) does not address moving walkways. It is prudent to calculate emergency evacuation flow under the assumption that power is off. Note that a moving walkway under repair, like an escalator under repair, would not be available for walking.

VERTICAL CIRCULATION

Stairways

Levels of Service for Stairways

Stairway LOS thresholds for transit facilities are different from those given in the HCM.

The required width of a stairway is based on maintaining a desirable pedestrian LOS. Stairway levels of service are based on average pedestrian space and average flow rate. Exhibit 10-29 summarizes the LOS thresholds for stairways. The threshold between LOS E and F (17 p/ft/min or 56 p/m/min) represents the capacity of a stairway. Note that these thresholds differ from those given in the HCM 2000 (*17*); the thresholds given in Exhibit 10-29 are ones typically used for transit facilities.

Exhibit 10-29
Stairway LOS

LOS	Avg. Ped. Space (ft^2/p)	Avg. Ped. Space (m^2/p)	Flow per Unit Width (p/ft/min)	Flow per Unit Width (p/m/min)	Description
A	≥ 20	≥ 1.9	≤ 5	≤ 16	Sufficient area to freely select speed and to pass slower-moving pedestrians. Reverse flows cause limited conflicts.
B	15-20	1.4-1.9	5-7	16-23	Sufficient area to freely select speed with some difficulty in passing slower-moving pedestrians. Reverse flows cause minor conflicts.
C	10-15	0.9-1.4	7-10	23-33	Speeds slightly restricted due to inability to pass slower-moving pedestrians. Reverse flows cause some conflicts.
D	7-10	0.7-0.9	10-13	33-43	Speeds restricted due to inability to pass slower-moving pedestrians. Reverse flows cause significant conflicts.
E	4-7	0.4-0.7	13-17	43-56	Speeds of all pedestrians reduced. Intermittent stoppages likely to occur. Reverse flows cause serious conflicts.
F	≤ 4	≤ 0.4	*Variable*	*Variable*	Complete breakdown in pedestrian flow with many stoppages. Forward progress dependent on slowest moving pedestrians.

Source: Fruin (*2*).

Evaluation Procedures

Critical passenger flows on stairways occur in the ascending direction.

The LOS thresholds for stairways (Exhibit 10-29) are based on average flow rates. The threshold between LOS E and F (17 p/ft/min or 56 p/m/min) represents the maximum capacity of a stairway.

When designing stairways, the following factors should be considered (*2*):

- Where possible, the number and width of stairs should be planned to minimize the duration of queues or avoid queuing altogether;
- Clear areas large enough to allow for queuing pedestrians should be provided at the approaches to all stairways;
- Riser heights should be kept below 7 in. (0.18 m) to increase safety, passenger comfort, and traffic efficiency; and
- When a stairway is placed directly within a corridor of the same width, the stairway will have a lower pedestrian capacity than the corridor and will be the controlling factor in the design of the walkway section.

When minor, reverse-flow traffic volumes frequently occur on a stair, the effective width of the stair for the major-direction design flow should be reduced by a minimum of one traffic lane, or 30 in. (0.75 m).

The following steps are necessary to calculate the width of stairway, stairway capacity, and queuing area required for a given peak pedestrian volume.

Determining Required Stairway Width by the LOS Method

This procedure to determine the required stairway width is based on maintaining a desirable pedestrian LOS. For normal use, it is desirable for pedestrian flows to operate at or above LOS C or D. However, in most modern terminals, escalators would be provided to accommodate pedestrians. Stairs, therefore, are typically provided as a supplement to the escalators to be used when the escalators are over capacity or out of service due to a mechanical failure, maintenance outage, or power failure. Under these circumstances, maximum stair capacity, or LOS E (17 p/ft/min or 56 p/m/min) may be assumed. Pedestrian characteristics at a stair location should be incorporated into the analysis.

The following steps are recommended for determining the required stairway width using the LOS method:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 10-29.
2. Select an analysis period appropriate to the location.
3. Estimate the directional pedestrian demand for the stairway for the analysis period.
4. Compute the design pedestrian flow (persons/minute) by dividing the demand by the number of minutes.
5. Compute the required width of stairway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Increase the stairway width by a minimum of one traffic lane (30 in., or 0.75 m) when minor, reverse-flow pedestrian volumes occur frequently.

Determining Required Stairway Width by the Pedestrian Lanes Method

Studies and observations indicate that pedestrians tend to form "lanes" when walking on stairs. The LOS approach to analyzing stairs described above results in a linear relationship between stair capacity and stair width and assumes that increasing or decreasing the width results in a proportional increase or decrease in capacity, even when the change in width is small. Analyzing stair capacity based on lanes suggests instead that stair capacity is not linear but is more stepped, such that adding a few inches (cm) has little effect on capacity, but that increases in capacity occur mainly when the width of a pedestrian lane is added.

When measuring lanes, the width taken by handrails must be considered. Two approaches are possible, based either on the clear width between handrails or based on the full width of the stairway. For the purposes of this method, it is recommended that the width of the stair be assumed to be the lesser of the width of the stair tread or the width between the handrails plus 3 in. (7.5 cm) on each side to account for some shoulder and elbow room over the handrails.

Observations and survey data (*30*) indicate that where circumstances dictate, people may move in lanes as narrow as 21 in. (53 cm) wide, but at such narrow widths, there is considerable friction and side-to-side contact. Generally free flow occurs in

lanes of 28 to 30 in. (71 to 76 cm) in width (including handrail width). A marked increase in capacity is observed when stair lane width increases from 26 in. (66 cm) to 28 in. (71 cm). Some additional peak capacity was observed with lanes between 31 and 33 in. (79 to 84 cm) in width.

Items carried by passengers also play a role in the effective width of pedestrian lanes. One or a few individuals carrying items are unlikely to significantly affect the capacity or effective width of a lane, unless they are significantly hindered by a large item, which would cause a temporary impediment to flow. However, if the population using a particular stair is prone to carrying items such as briefcases, shopping bags, or luggage, the effective width of pedestrian lanes will increase and the capacity of stairs minimally capable of carrying two lanes of people would decline. This likely explains the additional capacity observed on stairs with lanes between 31 and 33 in. (79 to 84 cm) in width.

Exhibit 10-30 summarizes the capacity of stair lanes by width. As personal spacing and items carried vary by location, it is recommended that users conduct counts in their locale for similar types of activities to establish appropriate lane widths and capacities for their application.

Exhibit 10-30
Stair Lane Width and Capacity

Lane Width		Approximate Capacity	
in.	cm	(p/min/lane)	Comments
21–27	53–70	30	Notable friction, not recommended for daily use
28–30	71–78	38	Recommended for general use
31–33	79–85	42	Provides extra space and slightly greater capacity
≥34	≥86	Little or no additional capacity	May be beneficial where pedestrians carry items

Determining the Number of Lanes for a Specific Stair Width

For an existing stair, observations during peak-volume periods will indicate the number of lanes that pedestrians naturally form on the stair. For planning a new stair, it should be assumed that people will create lanes approximately 28 to 30 in. (71 to 76 cm) wide. Lanes less than this width will generally only occur when the space between handrails is insufficient for two 28-in. (71-cm) lanes. For example, a stair that is 72 in. (183 cm) wide will generally operate as two generous lanes, not as three lanes averaging 24 in. (61 cm) in width. When a stair width could create three lanes of approximately 27 in., the development of two or three lanes may vary over time and may be affected by the steepness and rise of the stair, since people in the middle of a stair do not have access to a handrail.

Determining Maximum Stairway Capacity

As discussed above, the maximum capacity of a stairway is taken to be 17 p/ft/min (56 p/m/min), or LOS E. Therefore, for a given stairway width, the following steps may be used to compute the capacity:

1. Compute the design pedestrian flow (p/min) by multiplying the width of stairway by 17 p/ft/min (56 p/m/min).
2. Adjust for friction due to bi-directional flows by deducting 0 to 20%, depending on the pattern of flows. Little or no deduction should be applied when all flow is in one direction or when flows are fairly balanced. Up to a 20% deduction may be appropriate for conditions with a relatively small reverse direction flow.

3. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

Determining Required Size of the Stair Queuing Area

- Compute the stairway capacity using the above procedure.
- Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the stairway at one time.
- Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
- Compute the required queuing area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

Effect of Stair Rise on Capacity and Flow Rates

Studies have shown that as stair rise increases, pedestrians tire and slow down, reducing the flow rate on taller stairs. The rates and calculations presented above are generally applicable for stairs of up to about 15 ft (4.6 m) of vertical rise, though some difference may appear even within that range. When stairs of greater rise are under consideration, studies may be performed to determine the effect of greater heights on a specific population. It should also be noted that a route that passes through sequential stairs in relatively close succession will experience some of the effect of the overall rise, even though individual stairs may be shorter.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for stairs, stopped escalators, and ramps over 4% slope should be used in place of the values presented above. In the 2010 edition, these values were the following for both the up and down directions: a pedestrian flow rate of 1.41 persons per inch per minute (0.0555 p/mm/min), and a vertical component of travel speed of 48 ft/min (15.0 m/min) (*1*). Exit stairs should be a minimum 44 in. (1.12 m) wide. The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

Escalators

Escalator Capacity

Escalator manufacturers rate the maximum theoretical capacity of their units based on 100% step utilization. Observations indicate, however, that 100% utilization is never obtained. In general, passengers use alternate steps, leaving one step between them and the person in front of them (*2*). Because 100% utilization is typically not attainable, nominal design capacity values have been developed (see Exhibit 10-31). These values represent a step utilization of one person every other step on a 24-in. (0.6-m) wide escalator and one person per step (or two people every second step) on a 40-in. (1.0-m) wide escalator. Note that the capacity of medium-width escalators with 32-inch (0.8 m) steps have been observed to have peak occupancy close to the capacity of a double width escalator because people tend to stagger themselves on alternate steps on these escalators.

Exhibit 10-31
Nominal Escalator Capacity Values

Type	Width at Tread (in.)	Width at Tread (m)	Incline Speed (ft/min)	Incline Speed (m/min)	Nominal Capacity (p/h)	Nominal Capacity (p/min)
Single width	24	0.6	90	27.4	2,040	34
			120	36.6	2,700	45
Double width	40	1.0	90	27.4	4,320	72
			100	30.5	5,100	85
			120	36.6	5,400	90

Sources: Fruin (*2*), unpublished New York City Transit data.

Determining the Required Number of Escalators

The procedures to determine the required number of escalators are based on the width and speed of the escalator being considered. The following is a list of steps suggested for determining the required number of escalators:

1. Determine an analysis period appropriate to the location of 15 min or less.
2. Estimate the directional pedestrian demand for the escalator for the analysis period.
3. Compute the design pedestrian flow (pedestrians per minute) by dividing the demand by the number of minutes.
4. Based on the width and speed of the escalator, choose the nominal capacity (pedestrians per minute) from Exhibit 10-31.
5. Compute the required number of escalators by dividing the design pedestrian flow by the nominal capacity of one escalator, rounding up.

Determining Required Size of the Queuing Area

The possibility that escalators can generate large queues, even at pedestrian demands below nominal capacity, should be considered. Queues may generate when demand exceeds capacity or when pedestrian arrival is intermittent or persons are carrying baggage or luggage. For these situations, an adequate queuing area should be placed at the approach of an escalator based on an average pedestrian space of 5 ft^2 (0.5 m^2) per person. (Where alternative stationary stairs are conveniently available, the maximum wait time for an escalator may be reduced somewhat, but unless specific data are available, it should be assumed that most people will wait for an escalator.) Sufficient space should also be provided at the discharge end of an escalator to avoid conflicts with other traffic streams. The following are steps for computing the required size of a queuing area at the approach to an escalator:

1. Determine the capacity of the escalator from Exhibit 10-31.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the escalator at one time.
3. Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
4. Compute the required queue area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 standard allows both stopped and running escalators, equipped to operate in both directions, to be

considered as emergency exits. The 2010 NFPA 130 values for stopped escalator capacity and pedestrian travel speed may be found in the preceding section on stairways. A double-width escalator is generally assumed to have a usable with of 44 in. (1120 mm) for NFPA 130 analysis. Escalators shall not account for more than one-half of the exit capacity, and one escalator shall be considered to be out of service at each level (*1*).

Elevators

Elevator Level of Service

The LOS of an elevator system is typically based both on wait time and on the level of crowding. The tolerance level for an acceptable waiting time for elevator service at a transit terminal is around 30 s but also depends on the vertical distance traveled and alternate means. Average pedestrian space will be less important, unless inadequate capacity causes excessive crowding or causes people to miss an elevator, increasing their travel time and raising frustration. It is important to consider the maneuverability of wheelchairs in an elevator. This is particularly important in crowded situations or where the person using a wheelchair needs to turn to access the control panel or to exit.

Elevator Waiting Time

In evaluating wait time for an elevator, both the maximum and average wait times can be measured. The maximum wait time with a single elevator is the cycle time for the elevator to depart, make one or more intermediate stops, and return to its starting point ready to return in the initial direction. This represents the time spent by a person who arrived just as the elevator doors were closing but was unable to board. The average waiting time will generally be half of the cycle time. The effect on waiting times of multiple elevators depends on the coordination of their operation. If electronic controls space elevator departures, waiting times will be reduced by a factor of the number of elevators. In practice, the reduction is usually somewhat less, particularly if passengers hold elevator doors.

Elevator Capacity

The capacity of an elevator system depends on the following four factors:

- Entering and exiting patterns of users;
- User characteristics, including luggage, strollers, bicycles, and wheelchairs;
- Elevator travel time; and
- Practical capacity of the elevator cab.

Boarding and alighting times will depend on the door width and whether passengers are carrying baggage or luggage. The number of passengers boarding may also affect boarding rates. Studies that have investigated boarding rates for transit vehicles have found that boarding rates increase as the number of passengers increase due to “peer pressure.” To determine average boarding and alighting times for a particular elevator system, it is recommended that field data be collected.

Elevator travel time will be based on the operating characteristics of the elevator, including the following:

- Distance traveled (height of shaft),
- Elevator speed,
- Elevator acceleration and deceleration rates, and
- Elevator door opening and closing times.

The above factors will remain constant for a particular elevator system. The practical capacity of an elevator in a transit station will be based on the following:

- Presence of heavy winter clothing, and
- Presence of baggage or luggage.

The presence of heavy clothing, bags, or luggage increases the required area per person and, therefore, reduces standing capacity. Although the crush capacity of an elevator is approximately 1.8 ft^2 (0.17 m^2) per person, most people require 3.0 ft^2 (0.28 m^2) or more to feel comfortable in an elevator and this is a suitable design standard. As mentioned above, riders of elevators are more willing to accept less personal space due to the short time period associated with the elevator ride. Provision for baggage is particularly important at stations serving airports or intercity bus or rail terminals and at other stations along lines serving those facilities.

Designing for Emergency Evacuation

The 2010 edition of NFPA 130 (*1*) allows the use of elevators for evacuation when certain design requirements are met to promote their continued operation during adverse conditions. Elevators may not constitute more than 50 percent of the required egress capacity, at least one elevator must be assumed to be out of service, and one elevator must be reserved for fire department use. In addition, a holding area must be provided that meets requirements put forth in NFPA 130.

Ramps

Ramp Level of Service

LOS thresholds have not been established for ramps, but they would be comparable with those for walkways.

Evaluation Procedures

In many applications, ramps are considered auxiliary to the main circulation routes in a station, provided to serve only a small portion of a station's total users. In these cases, their capacity will not be critical to the analysis of passenger flow and they need not be evaluated in terms of LOS. Where ramps are used in place of stairs as a primary pedestrian circulation element, they can be treated much like level walkways. Grades of up to 6% have been found to have negligible effect on pedestrians, while a slope of 10% has reduced speeds by about 12%.

Designing for Emergency Evacuation

The 2010 NFPA 130 standard (*1*) specifies ramp capacities and pedestrian travel speeds for use in emergency evacuation design that are the same as those for walkways.

PLATFORMS AND WAITING AREAS

Levels of Service for Bus Stops and Station Platforms

Levels of service for passenger queuing and waiting areas, such as station platforms, are shown in Exhibit 10-32. The thresholds were developed based on average pedestrian space, personal comfort, and degrees of internal mobility. LOS is presented in terms of average area per person and average interpersonal space (distance between people).

The LOS required for waiting within a facility is a function of the amount of time spent waiting, the number of people waiting, the waiting pattern (in a queue versus looser standing),and a desired level of comfort. Typically, the longer the wait or the looser the waiting pattern, the greater the space per person required. A person's tolerance of a level of crowding will vary with time. People will accept being tightly packed on an elevator for one minute, but not in a waiting area for 15 minutes (*17*).

A person's acceptance of close interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, commuters may be willing to accept higher levels or longer periods of crowding than intercity and recreational travelers (*17*).

Exhibit 10-32
Levels of Service for Queuing Areas

LOS	Average Pedestrian Area (ft^2/p)	Average Pedestrian Area (m^2/p)	Average Inter-Person Spacing (ft)	Average Inter-Person Spacing (m)
A	≥ 13	≥ 1.2	≥ 4.0	≥ 1.2
B	10–13	0.9–1.2	3.5–4.0	1.1–1.2
C	7–10	0.7–0.9	3.0–3.5	0.9–1.1
D	3–7	0.3–0.7	2.0–3.0	0.6–0.9
E	2–3	0.2–0.3	<2.0	<0.6
F	< 2	< 0.2	*Variable*	*Variable*

Source: *Fruin (2)*.

The typical design LOS used for bus stops and station platforms is LOS C to D or better. Passenger congestion in the LOS E range is experienced only on the most crowded elevators or transit vehicles. LOS D represents crowding with some internal circulation possible; however, this LOS is not recommended for long-term waiting periods. The presence of passengers who use wheelchairs, strollers, or bicycles, or carry luggage or packages should be assessed and suitable provision made in station space.

Platform Usage

The shape and configuration of a station platform is dictated by many systemwide factors. Platform length is typically based on transit vehicle length and the number of transit vehicles using the platform at any one time. Platform width is dependent upon structural considerations, passenger queuing space, circulation requirements, and entry/exit locations.

Transit platforms can be divided into the following areas (*20*):

- Walking areas;
- Waiting areas;

- Waiting area buffers (adjacent to the platform edge and to waiting areas), with the platform edge denoted by a 18-in. (0.5-m) detectable warning strip;
- Dead areas between bus loading areas or train doors;
- Space taken up by seats, pillars, and other obstructions; and
- Queue storage.

Exhibit 10-33 illustrates the use of these areas for a transit platform serving buses.

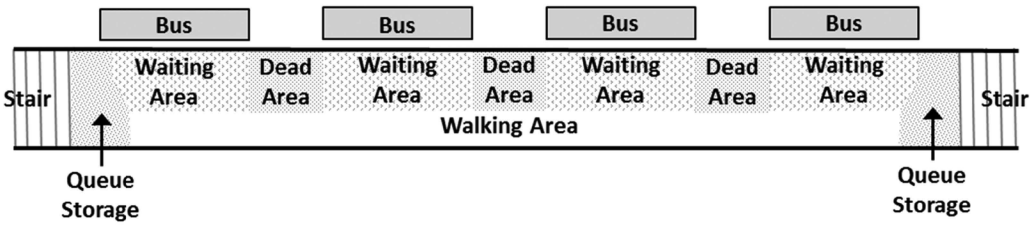


Exhibit 10-33
Transit Platform Areas

Source: Benz (*20*).

There are several different platform components which impact capacity and size requirements.

Walking and waiting do not occur evenly over the platform area. Some areas are used primarily for walking (e.g., near entry/exit locations and along the back edge of the platform) while other areas are used primarily for waiting (e.g., loading areas). Areas that are generally not used by passengers are termed *dead areas.* These areas are typically present between buses at a bus terminal or in front of or behind a train at a rail station. Dead areas should be taken into consideration when choosing the size and configuration of a platform. Where a platform serves multiple routes, special consideration should be made of passengers who will continue to wait on the platform until their train or bus arrives.

Platform Sizing

Evaluation Procedure

The procedures to determine the size of a transit platform are based on maintaining a desirable pedestrian LOS in the waiting and circulation areas, while providing needed buffer space and reserving space for physical objects, such as staircases or seating. The following is a list of steps recommended for determining the desired platform size:

1. Based on the desired LOS, choose the corresponding average pedestrian space from Exhibit 10-32;
2. Adjust as appropriate for passenger characteristics (e.g., wheelchair usage, luggage, bicycles);
3. Estimate the maximum passenger demand for the platform at a given time;
4. Calculate the required waiting space by multiplying the average space per person by the maximum passenger demand;
5. Calculate the additional walkway width needed to serve arriving passengers by using the appropriate procedures for walkways described previously;
6. Calculate the queue storage space required for exit points (at stairs, escalators, and elevators) as described previously;

7. Consider the additional platform space that will be unused, including dead areas and physical obstructions;
8. Add a buffer zone to the width of the platform (18 in., or 0.5 m, on each side having direct access to a roadway or trackway) ;
9. Calculate the total platform area by summing the required waiting space, walkway width, queue storage at exit points, dead areas, and buffer zone width; and
10. Apply a safety or growth factor if appropriate.

The result of this calculation will be a minimum platform area required to meet demand. Actual platform area and dimensions may be determined by other factors, such as minimum clearances and architectural considerations, especially in low- to medium-volume stations. Calculation Example 3 later in this chapter demonstrates the application of this process.

Designing for Emergency Evacuation

NFPA 130 does not directly affect overall platform area unless obstacles, such as a stairway or open platform edge, require additional platform width to provide egress capacity past the obstacle (*1*). The standard specifies that egress routes must be at least 44 in. (1.12 m) wide. When such a route passes between an open platform edge, an additional 18 in. (450 mm) must be provided. When a route passes a sidewall or obstacle such as a stairway, an additional width of 12 in. (300 mm) must be provided. With both an open platform edge and a sidewall, a total width of 74 in. (1.87 m) would be required.

Shelters and Waiting Rooms

Level of Service

No specific LOS has been suggested for shelters, waiting rooms, or seating. The space provided within shelters or waiting rooms can be assessed using the LOS thresholds for queuing spaces, as presented in Exhibit 10-32. These thresholds are based on average pedestrian space, personal comfort, and degrees of mobility within the space. However, local circumstances must be taken into consideration when determining what the projected or desirable occupancy is, since such spaces are rarely used by all passengers and may only be used to the maximum extent on limited days of the year, depending on local climates. For example, shelters may be used on a daily basis for 6 months of the year in a colder northern climate but may be used only a few days a month in warmer, dryer climates. As a result, it may be more desirable to handle full stop or station loads in the more adverse climate, but provide more limited capacity relative to station passenger volumes where the shelter is used less often.

Evaluation Procedures

The LOS for persons standing in a shelter or waiting room may be assessed using the LOS criteria for queuing spaces, as presented in Exhibit 10-32. In larger waiting rooms where circulation is to be maintained or other activities such as ticket selling are occurring, the time-space analysis approach described in Equation 10-4 and Equation 10-5 can be applied or a pedestrian simulation software applied. A simpler analysis

could be conducted using a space per pedestrian that is between the walking criteria shown in Exhibit 10-28 and the queuing criteria presented in Exhibit 10-32.

The desirable number of seats is a question of the maximum number of people who would choose to sit, the average waiting time, and such design issues as the space available for seating and the cost of installing and maintaining seats. One approach to assessing the desired number of seats in an existing station is to temporarily locate more than the anticipated number of seats in a station, using movable stacking chairs, and count the number of people who choose to sit in them during peak periods. The temporary seats can then be replaced with permanently mounted seats and benches.

INTERACTIONS BETWEEN STATION ELEMENTS

To maximize flow through the various components of the pedestrian system, minimum "protected run-off" areas are often defined on either side of critical components. Critical components are typically considered to be doors and faregates, and on the approach to (and egress from) stairs, elevators, and escalators. Typically in the region of 15 ft (5 m), these run-off areas are intended to ensure that obstacles (including conflicting pedestrian movements) do not interfere with smooth pedestrian flow at these critical points within the pedestrian system. In the case of escalators, it is particularly important that egress paths are not blocked, for safety reasons.

ALTERNATIVE PERFORMANCE MEASURES FOR SIZING STATION CIRCULATION ELEMENTS

Passenger space and density has traditionally been a common measure used to size station circulation elements, particularly in combination with pedestrian LOS based on area per passenger. However, other performance measures can also be used for design. Three of these—volume-to-capacity (*v/c*) ratios, clearance time, and queue length/duration—are described in this section. Any of these methods may be used along with pedestrian LOS, pedestrian time-space, or microsimulation to address specific project concerns. The choice of method(s) will depend on the specific issues or concerns, available input data, and available schedule and budget for analysis. Multiple methods may be used together on the same or different areas of a station, or they may be used in sequence during project development, moving from simpler, less-demanding methods to more elaborate procedures.

Station capacity analysis entails various *methods* to calculate multiple performance *measures* or *metrics*. For some relatively simpler measures, a method using a computer spreadsheet can be applied. These simpler or aggregate measures can also be obtained from computer microsimulation. However, as discussed in the section on microsimulation, additional more-complex measures based on the *individual* experience of large numbers of people can be reported.

Volume-to-Capacity Ratio Analysis

All elements in a pedestrian network can be analyzed based on a comparison of pedestrian volume and capacity, expressed as a ratio of volume divided by capacity, or *v/c*. Some elements, including escalators, faregates, and ticketing machines are better analyzed in this way than in terms of LOS, in part because it may be considered acceptable for them to operate near capacity, at least for brief periods of time. Stairs and passageways can also be analyzed in this way instead of by the LOS method, when a

more refined numerical measure is desired. A *v/c* ratio less than one indicates that an element is operating at less than capacity, a *v/c* of 1.0 represents an element operating at capacity, and a *v/c* ratio greater than 1.0 indicates that an element is operating over capacity (or forecast to exceed capacity).

A key consideration in *v/c* analysis is defining the capacity of an element. Capacity may be defined in two fundamental ways: *maximum* capacity or *design* capacity. Maximum capacity represents the maximum number of people who can be processed by an element during a fixed time frame. This maximum number should be based on real-world behavior as measured by field counts, not a hypothetical capacity as sometimes expressed by equipment manufacturers. Estimating maximum capacity requires a situation in which a queue has developed at the entrance to an element and can be measured only as long as the queue exists. Where such a condition does not occur naturally, some manipulation, such as closing alternate routes, might be necessary to observe maximum capacity.

In contrast, design capacity represents a desirable maximum volume reflecting a busy, but comfortable condition and would normally be a somewhat lower volume than maximum capacity. The selection of a design capacity is usually arbitrary, but could be based on a user preference survey. It may also reflect the desire to plan for redundancy in the event of equipment failure or routine maintenance. Particularly in the case of faregates, it should be noted that maximum capacity, and perhaps design capacity, is influenced not only by the physical characteristics of the gate, but also by the characteristics of the fare system. Thus, identical faregates on different systems may have different capacities, and the capacity of existing faregates can change with a change in the fare system.

Platform Clearance Time Analysis

Platform exit capacity is a key consideration in heavily used stations.

Pulsed Nature of Pedestrian Flows from Platforms

The pedestrian LOS approach to analyzing flow normally considers a fixed time period and analyzes density based on average volumes over that period. However, pedestrian flows can be highly variable, particularly in a transit system where flows on certain elements occur in pulses immediately after the arrival of a transit vehicle. In these situations, passengers tend to move through some circulation elements based on the processing rate of the element rather than spread out over a period of time. For example, the calculation for sizing a stair serving a station platform can focus on the time required to clear the volume generated by each arriving train. The result for all exits from a platform is platform clearance time. Design objectives for platform clearance time can then be set for a variety of circumstances, including clearance of a platform or mezzanine, for both normal and emergency purposes.

General Approach to Platform Clearance Time Analysis

A key capacity analysis for larger transit stations is the platform exit capacity needed to accommodate passenger demands during the peak period. This capacity ensures that each station platform is clear before the next train arrives. The general solution is as follows:

$$\frac{\text{Passengers/train}}{\text{Capacity (passengers/minute)}} \leq \text{Train headway (minutes)}$$

Equation 10-6

or

$$\text{Capacity (passengers/minute)} \geq \frac{\text{Passengers/train}}{\text{Train headway (minutes)}}$$

Equation 10-7

Because people may not use, or be able to use, all available exits, some safety factor is needed. This could be as much as 20 to 30%. Where simultaneous arrivals or departures occur on both sides of a center platform on a regular basis, the passenger volume of both trains or buses should be considered.

Analysis by this method normally focuses on the one direction of flow affected by surges associated with transit arrivals. However, counter-flow must also be considered where appropriate (unless a circulation element only receives flow in the peak direction either due to controls on flow or transit operating circumstances). Where counter-flow occurs, it is usually assumed that at least one pedestrian lane is fully occupied by counter-flow, even if the volume is significantly less than the capacity of the lane.

Steps for Platform Clearance Analysis

The steps for a platform clearance analysis are as follows:

1. Determine the passenger volume departing the platform. This may represent a crush loaded train, a forecast disembarking volume, or a forecast peak load for emergency evacuation. Where two or more trains may be present, volumes should be combined.
2. Determine the distribution of passengers to various exit routes, including stairs, escalators, passages, and other routes to exit platforms.
3. For each stair, determine the number of lanes available for exiting and its total capacity per minute. If counter-flows to the platform will occur at the same time that people are leaving the platform after a train arrival, determine the number of lanes needed to serve counter-flow.
4. For each platform exit, divide the volume assigned to that element by its total capacity per minute. The result is the provisional clearance time for each element (in minutes). The maximum clearance time among all the exit routes is the platform clearance time.
5. Review the clearance time for all platform exits. Where passengers have multiple choices and clearance time from some elements is significantly less than other elements, consider reassignment to better balance clearance time. Note, however, that clearance time is rarely identical on all elements leading from a platform, due to unbalanced transit vehicle loadings, passenger preference for certain destinations outside the station, and other factors.
6. Recalculate the clearance time for each element and the platform as a whole based on the reassigned distribution from Step 5.

Excessive platform clearance time or excessive time on specific elements may suggest the need for additional exit capacity, which is added by introducing additional stair lanes (or other egress elements). At a maximum, platform clearance time should be less than the headway between train or bus arrivals. However, clearing platforms in less than the headway is not always adequate from the standpoint of passenger comfort and convenience and a shorter clearance time may be needed.

Queue Analysis

Queues occur in the transit environment in two ways: deliberate or incidental. Deliberate queues occur where people are waiting for a specific function, such as purchasing tickets or lining up at a vendor within the transit facility. The formation and direction of these queues may be controlled or influenced by stanchions, floor markings, or other elements, or they may be uncontrolled and variable. Incidental queues occur when a surge of passengers exceeds the capacity of available circulation elements, such as stairs, escalators, or fare gates. These queues tend to be more amorphous, with people joining from multiple directions and filling in available space.

Typical measures of queues include:

- The maximum area or extent of the queue (measured as the linear distance from the element causing the queuing);
- The delay or maximum amount of time spent in a queue per person (or per group of people), from the moment of entry to exiting the queue; and
- The duration of the queue, from the time it forms until it dissipates and returns to a free-flow condition where pedestrians walk at close to their desired speeds.

In the case of "deliberate" queues at service points (such as ticket vending machines or counters), it is important to understand the passenger arrival pattern at the service point, and the distribution of transaction times at that service point, in order to adequately assess potential queue propagation and spatial requirements.

6. APPLICATIONS

This section presents examples of some the real-world situations that this chapter's methods can be applied to. This chapter also discusses the use of pedestrian microsimulation as part of a station analysis. Detailed examples of some of this chapter's quantitative analysis methods are presented in Section 8, Calculation Examples.

ALTERNATIVE MODE AND ALIGNMENT COMPARISONS

The provision of stop, station, and terminal facilities is an important consideration at the systems planning level of selecting transit modes and alignments. While the details of final station locations and design need not be determined at this stage in project development, an understanding of the physical requirements for station facilities, their effect on the service provided to travelers, and their costs are integral to evaluating alternative modes and alignments.

The steps that might be applied in such an analysis are:

1. Identify the goals and objectives for the transportation improvements and revise these as needed.
2. Identify the modes to be considered, the general area to be served, and the initial alignments for each mode.
3. Determine typical and minimum requirements for stations for each mode, including such factors as length, width, allowable curvature, access for persons with disabilities, and passenger amenities. Develop one or more typical station layouts, such as for an at-grade, elevated, or underground station, or an on-street and off-street station, depending on the range of settings likely to occur in the study. This chapter provides information on the various station elements.
4. Determine desired station locations for each combination of mode and alignment based on relationship to destinations, operational considerations, and physical constraints. Adjust as required to address station requirements.
5. Determine which station locations can be served by a station of typical size and configuration, and locations where different station characteristics are required due to passenger volumes, physical constraints, or unique opportunities. Apply either a typical station configuration or a customized conceptual layout to each proposed station location.

With travel demand forecasts for each station, the methods of assessing the capacity of station elements presented in this chapter may be used to determine where a typical layout will suffice and where larger capacities may be required (or minimal features may suffice).

With conceptual station locations and layouts associated with each mode and alignment alternative, conceptual cost estimates can be developed and the environmental, community, and transportation impacts of the stations can be assessed along with the other elements of the project.

ALTERNATIVE STATION LOCATION AND FEATURES COMPARISONS

Once a mode, basic alignment, and conceptual station locations have been identified for a new transit facility or service, the development of station plans is advanced to a greater level of detail along with other elements of the project. The emphasis on station design is increasingly focused on meeting the projected demand and unique constraints and opportunities at each station location.

Similar to the steps in the previous application, the steps that might be applied to prepare station plans during project development are:

1. Keeping in mind the overall goals and objectives for the project, consider objectives for each station. These may consider the function of each station (entry/exit vs. transfers), character of the area served (walk-in/park-and-ride, residential/employment/mixed use), and community or stakeholder input.
2. If a typical station layout is to be applied for consistency and cost effectiveness, determine whether that layout will adequately serve the passenger volumes expected at each station using the capacity measures described in this chapter.
3. Where necessary or desirable, adjust the typical design or apply a unique design. In developing unique station designs, consider the effect of alternate features and layouts on passenger experience based on descriptions provided in this chapter and determine the required size and number of various station elements based on the capacity measures described in this chapter. Apply the requirements of NFPA 130 and the ADA to the design to provide for safe and accessible facilities.
4. At each stage of project development, determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to part or all of a station plan. The decision will revolve around the complexity of the issues and the design, the questions to be answered by the analysis, the data available for analyses, and the cost of the alternative approaches to analysis.
5. Adjust station locations as needed to satisfy design requirements or respond to other factors.

REMODELING AN EXISTING STATION

With age or changing conditions, existing transit stops or stations may become obsolete or deficient. New development next to a station might call for a new station entrance or result in a change to the pattern of use of the station. The issue or opportunity will be to reexamine the station in a comprehensive manner and address issues of capacity, design, and features.

The steps that might be applied to the development of plans for remodeling an existing station are:

1. Assess the current condition, layout, and function of the existing station. Collect detailed data on existing passenger flows. Project future changes to passenger demands.
2. Develop one or more alternative concepts for addressing existing and projected future demands and for improving the passenger experience.

3. Apply the requirements of NFPA 130 and the ADA to the design to provide for safe and accessible facilities and to verify the design's compliance with these standards.
4. Determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to part or all of a station plan. The decision will revolve around the complexity of the issues and the design, the questions to be answered by the analysis, the data available for analyses, and the cost of the alternative approaches to analysis.

ADDRESSING A SPECIFIC CAPACITY ISSUE IN AN EXISTING STATION

Daily experience may indicate a localized capacity issue within a station while most areas of the station functions adequately. For example, a particular stair, escalator, or corridor may experience excessive delays and congestion under certain frequent conditions (such as just after arrival of trains or buses). The steps that might be applied to evaluating a capacity issue within an existing station are:

1. Assess the nature of the existing issue. Measure the capacity of elements in the area of concern using methods described in this section and record peak-flow volumes. Collect detailed data on existing passenger flows and project future volumes or allow for a margin of growth.
2. Develop one or more alternative concepts for addressing the existing circulation issue and allowing for projected growth. Note that improvements to address capacity issues may involve changes to the elements where issues are observed, or they may be applied in a different area as long as it would provide relief to the areas of concern. For example, relieving a stair or escalator that experiences congestion could be addressed by widening the stair or adding an adjacent escalator, or it might be addressed by adding vertical circulation in another area of the station where it would divert patrons from the area of concern.
3. Check for compliance with the requirements of NFPA 130 and the ADA. Note that localized improvements may or may not require full compliance for the station, but in any case should not make the condition worse or less-compliant with those standards.
4. Determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to a portion of the station adequate to assess the effects of the improvements on passenger flow. Note that analysis of smaller areas may be well suited to a simulation model as the data and model building required are commensurately smaller as well.

COMPREHENSIVE ANALYSIS OF PASSENGER CIRCULATION

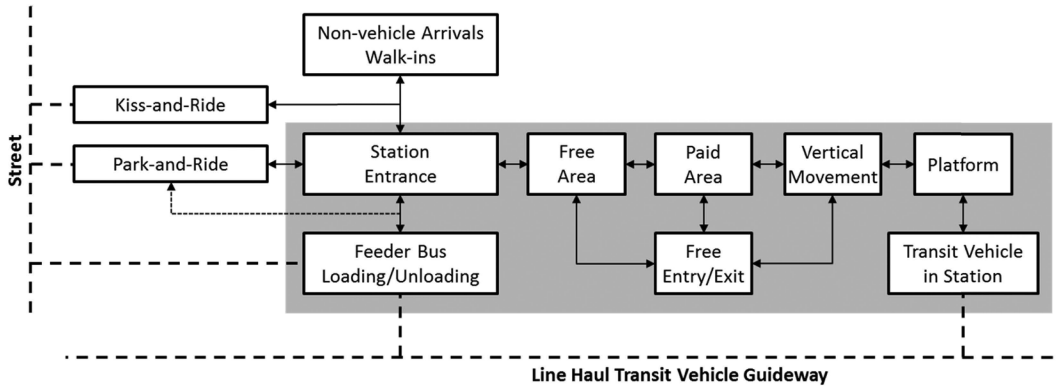
Comprehensive analysis of passenger flow in a station applied using a systems approach.

The more complex a station and its functions, the more complex its planning and design will be. A systematic approach can be taken with more complex stations. Multiple levels in a station present particular challenges, but also opportunities. The capacity of a station and its elements to carry passenger volumes are important. However, other aspects should be considered as well, including the clarity of station layout and wayfinding, access for persons with disabilities, and integrating the station with the surrounding community.

Pedestrian System Requirements

An initial step in evaluating a transit station design is to outline the pedestrian system requirements. Determining passenger circulation and queuing requirements begins with a detailed understanding of the pedestrian flow process through a station in the form of a flowchart. Exhibit 10-34 presents a sample flow diagram, although the elements and their order depend on the particular station. Properly done, the system diagram serves as a checklist and a reminder of the interrelationship of the various functional elements of the station. Exhibit 10-35 shows possible elements and components to be considered in a system diagram for the evaluation of pedestrian flows at a transit station.

Exhibit 10-34
Sample Pedestrian Flow Diagram Through a Transit Terminal



Source: Demetsky et al. (*31*).

Exhibit 10-35
Elements of Passenger Circulation in a Transit Station

Element	Components
Train Arrival	On- or off-schedule; train length; number and locations of doors
Passengers	Number boarding and alighting; boarding and alighting rates, passenger characteristics; mobility device use, baggage or packages carried, bicycles and strollers, etc.
Platform	Length, width, and effective area; locations of columns and obstructions; system coherence: stair and escalator orientation, lines of sight, signs, maps, and other visual information
Pedestrians	Walking distance and time; numbers arriving and waiting; effective area per pedestrian; levels of service
Stairs	Location; width; riser height and tread; traffic volume and direction; queue size; possibility of escalator breakdown
Escalators	Location; width; direction and speed; traffic volume and queue size; maintainability
Elevators	Location; size and speed; traffic volume and queue size; maintainability; alternate provisions for disabled passengers when elevator is non-functioning

After the system elements have been described schematically, they should be described quantitatively. Often this can be done following the same basic format and sequence as the system description. Pedestrian volumes can be scaled to size and

plotted graphically to illustrate volume and direction. Pedestrian walking times, distances, and waiting and service times can also be entered into this diagram.

The characteristics of users at a particular station should be assessed and considered in planning and design. Passenger characteristics include such factors as trip purpose, regular use (commuters) versus new or infrequent users, persons with disabilities, age stratification, and so forth. Trip purpose will relate to whether passengers carry luggage, packages, recreational equipment, or other items.

Comprehensive Passenger Circulation Analysis

The proximity of various station components to each other and the number of transit passengers those components must process impact station capacity. To allow a comprehensive assessment of the interaction of different station components on capacity, a broader evaluation of the pedestrian network should be conducted for larger, more complex stations. Simulation models can assist in the evaluation of alternate transit station designs as to their ability to effectively process transit passengers within defined parameters.

Manual Method/Input to Simulation Models

In the absence of a transit station simulation model, a basic assessment of the interactions of different station components on capacity can be assessed by establishing and evaluating a link–node network (*32*). These network data also serve as typical inputs into computer simulation models. The methodology includes the steps described below.

Step 1: Define the System as a Link–Node Network

Paths passengers take through a terminal (origin–destination pairs) are transformed into a network of links and nodes. Each link, representing a horizontal and/or vertical circulation element, is described by four factors: (*a*) type—walkway, ramp, stairway, escalator, or elevator; (*b*) movements allowed—one-way or two-way (shared or not shared); (*c*) length—in feet or meters; and (*d*) minimum width—in feet or meters. Nodes are queuing points and/or decision points. They are typically fare collection devices, doors, platform entrances or exits, vertical circulation elements, and junctions of paths.

Step 2: Determine Pedestrian Volumes for the Identified Analysis Period

For each pedestrian origin–destination pair within a station, a pedestrian volume is assigned for the identified analysis period (typically the peak hour or the peak 5 to 15 min within the peak hour). Origin–destination pairs distinguish between inbound and outbound passengers. Adjustments may be made as appropriate for passenger characteristics.

Step 3: Determine Path Choice

The particular path or alternate paths that a passenger can or must traverse between a particular origin and destination pair (for both inbound and outbound passengers) are identified.

Step 4: Load Inbound Passengers onto the Network

Inbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 5: Load Outbound Passengers onto the Network

Outbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 6: Determine Walk Times and Crowding on Links

To calculate the walk times and crowding measures on a link, the flow on that link should be adjusted to reflect peak-within-the-peak-hour conditions (typically 5 to 15 min).

Effective widths of links and nodes are the actual minimum widths or doorway widths. When a wall is located on one side of a corridor, 1.0 to 1.5 ft (0.3 to 0.5 m) is typically subtracted. A buffer of 6 in. to 1 ft (0.15 to 0.3 m) is typically subtracted on each side of obstructions within corridors, such as trashcans and low railings. A buffer of 6 in. (0.15 m) is typically subtracted for walls in stairwells because transit users on the outside often use handrails.

The adjusted flow is divided by the effective width to determine the number of pedestrians per foot or meter width per minute. For a given LOS, the average space mean speed can be identified from Exhibit 10-28 for walkways, Exhibit 10-29 for stairways, and Exhibit 10-31 for escalators.

Step 7: Determine Queuing Times and Crowding at Nodes

Passenger queues at critical nodes can be estimated either by observation or analytical means. Queuing patterns vary depending on specific conditions at each location, particularly the arrival pattern of people at the constrained point. For example, queuing may occur at platform stairs immediately after a train or bus arrives, but the duration may vary considerably.

Step 8: Determine Wait Times for Transit Vehicles

Wait times for transit vehicles are a key input to determining required queuing areas on platforms. A typical assumption used, when service is frequent (10 minute headways or less), is that average wait time is half the bus or train headway.

Step 9: Add Travel Time Components and Assess Overall LOS

Overall travel times for different origin–destination pairs can be totaled and averaged to identify an average passenger processing time through a particular transit station.

PEDESTRIAN MICROSIMULATION

Pedestrian simulation modeling made significant advances in the first decade of the 21st century, evolving from aggregate (network) models and initial programs where individuals occupied and moved between individual cells in a grid, to agent-based dynamic models representing individuals and allowing a full range of movement, speed, and interpersonal spacing. Similarly, the evolution of pedestrian "knowledge" and

replication of a range of pedestrian characteristics in any population has evolved, from simpler hydraulic models (in which pedestrian movement is governed solely by external forces) to agent-based models that capture individual human behavior as well as movement. In the latter type of model, "agents" represent individual people, to the extent that the programming provides them with individual characteristics and allows them to replicate the complexities of navigation by real-world pedestrians.

Models that use a grid or cell system are of two types. In most such programs, each cell is occupied by a single individual. In a smaller number of programs, much smaller cells are used so that a person is represented as occupying a group of cells. The one-cell-per-person configuration places significant limits on the movement and spacing of individuals in the model. First, the cell size must be set to represent typical (average) interpersonal spacing, so that two people occupying adjacent cells are spaced appropriately. However, preferred minimum spacing differs among people and actual spacing varies as circumstances dictate. Second, movement can only be in increments equal to the size of the cells and can only occur in one of eight directions, and therefore lacks the ability to model more subtle changes in direction.

Models that simulate the movement of pedestrians within a continuous space allow for much more flexible and accurate spacing between pedestrians and complete freedom of movement in terms of both speed and direction. Increasingly, commercial pedestrian modeling software programs have adopted a structure based on continuous space and movement characteristics associated with agents representing individuals.

The question of when it is advantageous to use simulation instead of traditional static analysis tools depends on the complexity of the area and the issues to be addressed, the available data and computer-aided design (CAD) plans, the cost of available software, and the time and budget available for the effort. In general, larger, higher-volume facilities with complex pedestrian flows will often justify simulation, whereas simpler, more-localized issues can be most efficiently addressed by traditional means. Areas where crowd safety is a concern or large investments are planned are also likely to call for simulation analysis. At the same time, setting up a simulation for a small area with simple volume data may be achievable quickly at reasonable cost.

Inputs to Simulation Models

As simulation models have become increasingly sophisticated, the inputs to them become more complex. While some basic inputs are required of any model, it is possible to tailor the level of detail and the required inputs to match the needs of a specific project or analysis. Typical inputs to a simulation model may include:

- A plan of the area to be analyzed, usually entered in one of the common CAD file formats. CAD files developed for other purposes normally require editing to make them readable by the software. Some cleaning is also desirable to remove details that do not contribute to viewing the simulation, to reduce file size, and to increase the speed of simulation.
- Pedestrian volume data are entered as an origin–destination matrix or other format suitable to the data available and the method of analysis. Input data may be broken down into time increments or left in aggregate form to be distributed over time by the simulation.

- Various timing schedules may be required to indicate such events as the arrival and departure of transit vehicles, pedestrian crossing signals, announcements or calls to board, elevator movements, and other periodic or timed events.
- Population profiles indicating movement characteristics such as walking speeds, preferred interpersonal spacing, and other factors may be selected from standard profiles provided by the software, or may be created based on survey data. In addition to representing cultural and regional differences, profiles can represent the different movement patterns of commuters, shoppers, attendees of different types of events, persons with various disabilities, or other groups.

Pedestrian routing within a model may be entered and adjusted manually in any microsimulation program, but most programs also have varying abilities to apply dynamic routing, either by manually creating controls that are then activated by conditions in the model, or performed more automatically by the software. This is an area of ongoing model development. The analyst should be aware of the capabilities and limitations of software to replicate real world routing and apply adjustments as needed to replicate observed or expected routing behavior as closely as possible.

Automated data collection methods (e.g., Bluetooth-based methods) are likely to become more commonplace in the future, offering the potential to make the data collection component of large-scale pedestrian movement studies much easier, more detailed, and more accurate. Such technology is already successfully used for highway surveys and has been trialed successfully in a transit context in London. Although the technology required more development at the time of writing for widespread use in the pedestrian survey context, early results were considered promising.

Outputs and Analyses Available with Pedestrian Microsimulation

In addition to better representing the complexity of pedestrian movement, pedestrian microsimulation offers outputs and facilitates measures of pedestrian flow and comfort not previously possible. Any of the basic measures discussed elsewhere in this chapter can also be derived from pedestrian simulation software. However, the software is able to aggregate the experiences of many agents instead of simply reporting averages, resulting in additional more advanced measures. Some of the basic measures that can be reported by pedestrian simulation software include:

- *Average density*—the size of a user-defined area divided by the number of individuals within it at any instant in time. It can be averaged and graphed across a time period. Note that an average density will include the entire area selected whether or not it is occupied.
- *Agent density*—the density perceived by individuals within the model. Unlike average density, agent density includes the spacing between each individual in the model with other individuals around that person, and only represents occupied space.
- *Flow volume* across a cordon line.
- *Travel time* from one cordon line to another.
- *Time to clear a zone* (such as a transit platform) defined by the analyst.
- *Instantaneous walking speed* passing a cordon line or for all people within a zone.

- *Number of people* within a zone.
- *Space utilization*—the amount of time during an analysis period that specific areas are occupied.

In addition, analyses that track an agent can develop a variety of measures specific to that agent over time (e.g., walking speed, personal density).

Simulation also facilitates more complex measures that consider more than one factor. The terms applied here are indicative of the intent, but both software programmers and analysts can define their own measures. Some possible measures include:

- *Convenience/Inconvenience*—the difference between preferred walking distance and actual walking distance due to diversions from the shortest path.
- *Fulfillment/Frustration*—the difference between a person's desired walking speed and actual walking speed, due either to congestion or waiting time.
- *Comfort/Discomfort*—the difference between a person's preference for personal space and the actual space density immediately around that person (as opposed to the average density for a group of people or all people in the model).
- *Satisfaction/Dissatisfaction*—a holistic measure of each person's experience compared to his or her respective preferences; dissatisfaction, for example, encompasses the elements of inconvenience, frustration, and discomfort.

Finally, simulations can generate global (whole model) measures that are best suited to overall comparison of alternative concepts or designs, including:

- *Weighted journey time*: a cumulative measure in which time spent in various activities (e.g., walking, climbing or descending stairs, waiting) is weighted based on factors representing personal perceptions of time spent in those activities. Weights can be adjusted by the analyst and different weighs can be applied for different classifications of people in the model, such as commuters and shoppers. It is expressed in units of time (hours or minutes).
- *Generalized cost:* a cumulative measure of the time spent in various activities, expressed in terms of money (based on values of time). In addition to weighting by activity type, weights can also be set for different classifications of people in the model.

Pedestrian simulations offer multiple means of summarizing and presenting data. The best choices for presentation will depend on the type of data and the issues addressed by the specific analysis. Available outputs include:

- Tables presenting quantitative measures over time, as instantaneous or cumulative values.
- Graphs in various formats presenting data representing instantaneous or cumulative values over time.
- Maps representing any measure spatially as instantaneous, mean, maximum, or minimum values. Color scales can be set to represent any increment of values. A common type of map represents mean densities on a color scale set to match LOS A through F.

- Video clips showing movements of people, changes in mapped data over time, or both. Movements of people can be represented either on a two-dimensional plan (usually as dots) or represented as realistic-looking three-dimensional individuals. Video can be recorded at a real-time rate or at an accelerated speed.

Maps commonly produced by pedestrian simulations include:

- *Cumulative High Density Map*: this map shows how long various areas of a site experience densities greater than a specified limit. The range of colors represents time. This map is best used for identifying "hot spots" within a site—areas where high levels of density are sustained. It asks the questions "is this design creating persistently uncomfortable crowd densities?" and "should the design be altered to alleviate these problems?"
- *Cumulative Max/Mean/Min Density Map*: this map displays the maximum, mean, or minimum levels of density registered in an area from the beginning of playback to the current moment. It is generally used in combination with value ranges corresponding to levels of service. It is best used for measuring the performance of an area against predetermined standards.
- *Evacuation Map*: this map represents the amount of time required to evacuate areas to defined points of safety. It is normally used in an emergency evacuation assessment, such as the time to clear a platform or station under emergency conditions. It can also be used for platform capacity assessments, to show how quickly platforms clear following the arrival of a train.
- *Space Utilization Map*: this map reveals how much space within a site is being used. It records the location of each agent over the duration of the simulation. Generally brighter colors represent greater space utilization. Areas of the simulation that are not used at all remain unshaded. The color range represents the amount of time a unit of space has been occupied within the simulation. These maps are useful in identifying areas where amenities such as benches or retail shops might be located.

Standards of Performance and Interpretation of Results with Simulations

As microsimulation has both introduced myriad ways to analyze pedestrian circulation, and also shed new light on traditional methods, it suggests a need for new standards for what constitutes preferred or acceptable pedestrian flow in various circumstances. Since simulations offer so many ways to summarize and present data, a key principle in applying these capabilities is to use only those outputs that relate to the issues or questions at hand, rather than "showing off" the capabilities of the software.

Design guidelines for transit systems or specific projects often indicate that a specific pedestrian LOS is to be maintained, generally LOS C or better for urban transit systems and, in some cases, LOS B for intercity rail passenger areas. Standards are often vague as to the duration of the period over which the LOS standard is to be achieved, although an average over the peak 15 min is most common or assumed by analysts. For area analyses, the configuration and size of analysis zones can significantly affect the average density and LOS, but is impractical to define in standards.

While pedestrian microsimulation software can be set to measure LOS, the software naturally provides a more fine-grained look at pedestrian flow and congestion because it can represent continuous or even momentary densities and because it presents densities throughout a space rather than applying analysis zones. This means that new or more-detailed standards for what constitutes preferred or acceptable pedestrian flow conditions are needed.

7. CALCULATION EXAMPLES

Exhibit 10-36
List of Calculation Examples

Example	Description
1	Suburban transit center design
2	Stairway sizing
3	Platform sizing
4	Escalator queuing area
5	Multiple pedestrian activities in a facility
6	Complex multilevel station
7	Application of pedestrian microsimulation software

CALCULATION EXAMPLE 1: SUBURBAN TRANSIT CENTER DESIGN

Based on a BRT planning study in the Vancouver, Canada region.

The Situation

A transit agency plans to construct a transit center in conjunction with a new freeway-based bus rapid transit route. The existing local routes in the area will be modified to feed passengers to the transit center. A large park-and-ride lot will also be provided at the station.

The Question

What is the design year (20-year future) berth requirement for the transit center?

The Facts

- The bus routes anticipated to use the center are listed in Exhibit 10-37, along with their projected headways in the design year.
- Bus routes terminating at the center will have approximately 50% of their layover time at the transit center if the other end of the route is also a transit center and approximately 75% otherwise.

Exhibit 10-37
Calculation Example 1: Bus Routes Planned to Use Proposed Transit Center

Route	Description	Transit Center Use	Peak Headway (min)	Total Route Recovery Time (min)	% Recovery at Transit Center	Recovery at Transit Center (min)
B	Freeway BRT all stop	Through	15	NA	NA	NA
B1	Freeway BRT all stop	Terminating	15	15	50%	8
BX	Freeway BRT express	Terminating	15	12	50%	6
F1	North/south frequent	Through	15	NA	NA	NA
F2	East/west frequent	Terminating	10	18	50%	9
L1	Local route	Terminating	20	12	75%	9
L2	Local route	Terminating	20	10	75%	8
L3	Local route	Terminating	20	14	75%	10
L4	Local route	Terminating	20	15	75%	11
L5	Local route	Terminating	20	24	75%	18

Note: NA = not applicable.

- Each direction of a route should be provided with its own boarding berth, except perhaps for variations of the same route.

- Much of the BRT ridership is anticipated to be park-and-ride based.
- Three versions of BRT service will be provided: (*a*) an all-stop route that starts in the center of a town bypassed by the freeway, (*b*) an all-stop route that begins at the transit center, and (*c*) an express route that runs non-stop the length of the freeway BRT facility.
- The local routes will have timed transfers with each other.
- One shared berth for dropping off arriving passengers on routes terminating at the transit center will also be provided for the more-frequent routes that cannot layover in a boarding berth.

Computational Steps

The process for off-street bus stops described in Section 4, Vehicle Circulation, and Storage, will be used to determine berth requirements.

Through Routes

Routes running through the transit center—B and F1—will require two boarding berths (one for each direction of the route). Therefore, a total of four boarding berths will be required for these routes.

Terminating Routes

The remaining routes terminate at the transit center. The number of required berths is based on the route's recovery time at the transit center, divided by the route headway, multiplied by a factor of 1.2 as an allowance for early-arriving buses, and rounded up. The first berth will normally be a boarding berth, with the remaining needs accommodated by layover berths.

As an example, Route F2 is planned to have a 9-min recovery time and a 10-min headway in the design year. The required number of berths is (9 / 10 × 1.2) = 1.1, which rounds up to 2. If the route ran perfectly to schedule, each bus would depart one minute before the next bus showed up (and therefore only one berth would be needed), but this level of reliability would not occur in actual operation. Therefore, two berths—one boarding and one layover—are needed to accommodate the likelihood of having two buses from the route in the transit center at the same time.

As a second example, Route L2 is planned to have an 8-min recovery time and a 20-min headway in the design year. The required number of berths for this route is (8 / 20 × 1.2) = 0.5, which rounds up to 1. Because only one berth is needed (i.e., it is very unlikely that more than one bus from the route will be in the transit center at the same time), this route's layover needs can take place in the boarding berth.

Exhibit 10-38 shows the resulting berth needs for all of the routes.

Exhibit 10-38
Calculation Example 1: Maximum Design Year Berth Needs

Route	Route Type	Peak Headway (min)	Recovery at Transit Center (min)	Berth Requirement	Berth Allocation: Boarding Berths	Berth Allocation: Layover Berths
B	Through	15	NA	0	2	0
B1	Terminating	15	8	0.6 → 1	0*	1
BX	Terminating	15	6	0.5 → 1	1	0
F1	Through	15	NA	0	2	0
F2	Terminating	10	9	1.1 → 2	1	1
L1	Terminating	20	9	0.6 → 1	1	0
L2	Terminating	20	8	0.5 → 1	1	0
L3	Terminating	20	10	0.6 → 1	1	0
L4	Terminating	20	11	0.7 → 1	1	0
L5	Terminating	20	18	1.1 → 2	1	1
			Maximum Berth Requirement		**11**	**3**

Notes: *This route would share the inbound Route B boarding berth.
NA = not applicable.

Because Route B1 operates the same as Route B inbound from the transit center (making all stops along the freeway BRT facility), it can use the same boarding berth as Route B. Since this berth cannot be used for layover (as the through-routed Route B also uses it), Route B1's berth requirement will be satisfied by providing a layover berth. All of the local routes except for L5 can layover in their boarding berth.

The Results

The resulting maximum berth needs are 11 boarding berths, 3 layover berths, and 1 passenger drop-off area for routes terminating at the transit center and not laying over in their boarding berth. If the site is constrained, the number of berths could potentially be reduced or reallocated as follows:

- Route BX could share the same inbound boarding berth as Routes B and B1. This would risk passenger confusion, as passengers might board a non-stop BX bus instead of the all-stop B or B1 bus they were intending to board (or less seriously, vice versa). In addition, the total number of berths required would not be reduced, as Route BX would still need a layover berth because the shared boarding berth would not be available for layover purposes. However, there might be more flexibility in where a layover berth could be placed within the site, compared to a boarding berth.
- Route F2's and L5's layover berths are only needed to accommodate early-arriving buses, because their recovery times are less than their headways. Therefore, the two routes could potentially share a layover berth that would only be used briefly until the preceding bus departed on schedule, freeing up the boarding berth for the early arriving bus's regularly scheduled layover. The risk is that buses from both routes would arrive early and there would not be enough berths to accommodate both buses.

CALCULATION EXAMPLE 2: STAIRWAY SIZING

The Situation

A new rail station will be constructed below grade. This three-level station (platform, mezzanine, and surface) will serve a new transit center and an adjacent urban university campus. The initial concept is to connect the single center platform to the mezzanine at two locations: at one end of the platform and halfway down the platform. A pair of double-width (40-in.) escalators with a stairway in between would be located at each platform access point. One elevator between each level would also be provided.

The Question

Based on the estimated demand under typical peak 15-min conditions and evacuation conditions, how wide should the stairways be?

The Facts

All values reflect design conditions 25 years in the future, rather than conditions when the station first opens.

- For the design year, four-car trains are expected to run at 7 to 8 min headways (i.e., 8 trains/h/direction).
- The a.m. peak hour exiting demand is estimated to be 3,200 passengers per hour. The corresponding a.m. peak-hour entering demand is estimated to be 500 p/h. The estimated p.m. peak-hour demands are 2,900 p/h entering and 500 p/h exiting.
- During the peak 15 min of the a.m. peak hour, the average inbound train entering the station will have 700 passengers on board, while the average outbound train will have 300 passengers on board. During the peak 15 min of the p.m. peak hour, the average inbound train entering the station will have 200 passengers on board, and the average outbound train will have 500 passengers on board.
- The maximum schedule load of a car is 200 passengers.
- The average peak-hour factor currently observed on the system is 0.714.
- The system operates on a proof-of-payment basis; thus, no fare gates are required.
- Sporting events are held at off-campus sites and do not impact peak-demand conditions at this station.

Computational Steps

Outline of Solution

LOS C is a reasonable design level for a station under typical daily conditions. The NFPA 130 evacuation standard (*1*) is conservative in its assumptions of the number of people that will need to be evacuated. The number of people that should be designed for includes:

- The loads of one train on each track during the peak 15 min, assuming each train is running one headway late (i.e., is carrying twice its normal load, but no more than a full [maximum schedule] load); and
- Passengers waiting on the platform to board trains during the peak 15 min, assuming their trains are running one headway late.

Conditions during both peak hours will be checked to see which controls different elements of the design. Next, the stairways will be sized to accommodate the design conditions during the peak 15 min. The resulting width will then be compared with the width required to evacuate the platform within 4 min. The larger width will control design.

Determining the Design Volume

Peak-hour volumes should be converted to peak 15-min volumes by multiplying by the peak-hour factor, as given in Chapter 2:

$$P_{15} = \frac{P_h}{4(PHF)}$$

For example, the peak 15-min exiting volume during the a.m. peak hour is:

$$P_{15} = \frac{3{,}200}{4(0.714)} = 1{,}120 \text{ p}$$

The corresponding peak 15-min entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak 15-min period, 1,015 passengers will be entering and 175 passengers will be exiting.

The number of people that may need to be evacuated is based on the train loads and passengers waiting to board. During the a.m. peak hour, this number is calculated from the following:

- *Inbound train*: an average train carries 700 people during the peak 15 min. A train operating one headway late would have a demand of twice this number, or 1,400 people, but only 800 of those people (the maximum schedule load of a four-car train) would actually have been able to board the train.
- *Outbound train*: an average train carries 300 people during the peak 15 min. A train operating one headway late would have a demand of twice this number, or 600 people, which is less than the train's capacity.
- *Waiting on platform*: At an average headway of 7.5 min between trains in a given direction, up to half of the entering volume during the peak 15 min typically would be present if the trains arrived on schedule. However, the design should assume that the trains are one headway late and, therefore, twice the typical number of waiting passengers should be used. This results in (175)(0.5)(2), or 175 people.

The total number of people to be evacuated during the a.m. peak hour is the sum of these three components, or 1,575 people. During the p.m. peak hour, the corresponding numbers are 400 inbound, 800 outbound, and 1,015 platform, for a total of 2,215 people.

The greatest exiting or entering volumes under typical daily conditions occur during the a.m. peak hour. The greatest number of people that may need to be evacuated occurs during the p.m. peak hour.

Sizing the Stairways

Exhibit 10-29 gives stairway pedestrian flows of 7 to 10 p/ft/min for a design LOS C. Because the users are commuters, the high end of the range can be used, resulting in the following stairway width:

$$\text{Stairway width} = \frac{1{,}120\,\text{p}}{15\,\text{min} \times 10\,\text{p/ft/m}} = 7.5\,\text{ft}\,(90\,\text{in.})$$

As the exiting volume is split between two stairways, each stairway would only need to be about 45 in. wide to serve exiting flows. An additional 30 in. should be provided for a lane to accommodate the small number of entering passengers, resulting in a total width of 75 in. for each stair.

Because escalators are being provided to supplement the stairs, the stairs would only be totally used in the event of unscheduled maintenance, power failures, or similar situations. Maximum stair capacity, or LOS E could be used:

$$\text{Stairway width} = \frac{1{,}120\,\text{p}}{15\,\text{min} \times 17\,\text{p/ft/m}} = 4.4\,\text{ft}\,(53\,\text{in.})$$

Dividing the result by two (because there are two stairways), and adding 30 in. to accommodate the small reverse flow, results in a total width of 57 in., which could be rounded up to the nearest foot (60 in.). Either width is greater than the NFPA minimum for an exit stair (44 in.).

Under emergency evacuation conditions, 2,215 people would need to be evacuated from the platform within 4 min. One of the four escalators should be assumed to be out of service. A stopped escalator can serve 1.41 p/in/min in the up direction, according to the NFPA 130 standard (1); thus a 40-in. escalator can serve (40 in.)(1.41 p/in./min), or 56 p/min. In 4 min, three escalators could serve (4 min)(3 escalators)(56 p/min/escalator), or 672 people, leaving 1,543 people to be served by stairs. The total stairway width required to serve these people in 4 min is:

$$\text{Stairway width} = \frac{1{,}543\,\text{p}}{4\,\text{min} \times 1.41\,\text{ped/in./min}} = 274\,\text{in.}\,(22\,\text{ft}\,10\,\text{in.})$$

The Results

The two stairways would need to be approximately 11.5 ft wide each. Evacuation needs, in this case, control the stairway size. Since these widths are much larger than needed for normal station operation, consideration might be given to supplementing the stairs with additional emergency stairways at the platform ends, allowing the regular stairs to be reduced in size, which would also result in a smaller overall platform width.

Although not addressed in this example, the evacuation capacity of the routes from the station's mezzanine level to the surface would also need to be evaluated. Further, the maximum time required for a passenger to reach a point of safety (generally either

the surface or a point beyond fire doors) would need to be evaluated. The NFPA 130 standard provides example calculations for these situations.

CALCULATION EXAMPLE 3: PLATFORM SIZING

The Situation

The same rail station that was subject of example 2 is used here. Based on the results of the previous example, it has been decided that the stairs between the escalators will be designed to provide LOS C conditions under normal station operations. Each stair will be 7.5 ft wide. Emergency stairs at the ends of the platform will provide the remaining required emergency evacuation capacity.

The Questions

Based on the estimated demand under typical peak 15-min conditions, how wide should the platform be? What would be the capacity of the platform to handle delayed train conditions?

The Facts

- The same conditions set forth in example 2 apply here.

Computational Steps

Outline of Solution

LOS C is a reasonable design level for a station under typical daily conditions. Design volumes for normal and emergency conditions were developed in Example 2. This example will demonstrate how these design volumes are used to determine a minimum platform size.

Sizing the Platform

Since arrivals exceed departures at the station in the morning and departures exceed arrivals in the evening, the peak platform condition in the station will be in the p.m. peak period when passengers are queuing on the platform to wait for trains. Therefore, the platform analysis will focus on that period. The steps given in the portion of Section 5 on sizing platforms will be followed:

1. *Choose a design pedestrian space.* To achieve LOS C, at least 7 ft^2/p is required for queuing space (from Exhibit 10-32) and at least 15 ft^2/p is required for walking space (from Exhibit 10-28).
2. *Adjust as appropriate for passenger characteristics.* No special characteristics (e.g., passengers with luggage) were identified; therefore, no adjustment is made in this case.
3. *Estimate the maximum passenger queuing demand for the platform.* Under typical conditions, with trains running on schedule, up to 507 passengers would be on the platform when trains arrived. (A total of 1,015 people enter the station during the peak p.m. 15 min, two trains arrive in each direction during the 15 min, and thus one-half of 1,015 people could be present.)

4. *Calculate the required waiting space.* Multiplying 507 passengers by 7 ft²/p results in a required area of 3,549 ft² under typical conditions. At the end of this process, non-typical conditions will be checked to make sure overcrowding will not occur.
5. *Calculate the additional walking space required.* Circulation area is required for arriving passengers to walk to the platform exits. This passenger demand is highly peaked, corresponding to individual train arrivals. During the p.m. peak 15 min, approximately 175 passengers will arrive on four trains. Approximately 70% of these passengers (500/700) will arrive on the two outbound trains, or about (175)(0.7)/2 = 61 passengers per outbound train. At an LOS C flow of 15 ft²/p, and assuming that three-quarters of the passengers from each train would be on the platform simultaneously results in total walking area of (61)(0.75)(15), or 686 ft².
6. *Calculate the queue storage space required for exit points.* From Exhibit 10-31, the capacity of a double-width escalator is 68 p/min at a typical incline speed of 90 ft/min. As two up escalators will be provided, the capacity provided (136 p/min) is much greater than the maximum p.m. peak demand (58 p/train); thus no queue should develop. See Example 4 for an example of how to calculate queue storage space.
7. *Consider the additional platform space that will be unused.* A typical rail transit car has multiple doors along its length, minimizing dead areas. However, an underground station with a center platform will have other unused platform space, including elevator shafts, stairs and escalators, benches, and potentially advertising or information displays, trash cans, or pillars. In this case, a total of 550 ft² will be assumed to be used by the central stairs and escalators, the elevator shaft, and assorted benches and displays, based on an initial design concept for the station.
8. *Calculate the required buffer zone.* A buffer 1.5 ft wide is required on each side of the platform. Since the platform needs to be 300 ft long to accommodate a four-car train, and buffers are required on both sides of a center platform, this results in a total of 900 ft².
9. *Calculate the total platform area.* Adding up the results of steps 4 through 8, and rounding, results in a 5,685 ft² platform area for LOS C conditions.

Based on the initial design concept, the platform would need to be at least 28.5 feet wide to accommodate the central stairs (7.5 ft, from above) and escalators (5 ft each), a 4-ft walkway on either side, and a 1.5-ft buffer zone adjacent to each track. This would result in a total platform area of 8,550 ft², which is much more than is required. (The tracks would typically be parallel through the station, to avoid creating gaps between the cars and the platform at the car doors.) The width could be reduced by placing the platform exit and entry escalators and/or the stairs in separate locations along the platform length.

The platform size can also be evaluated for non-typical situations. For example, if there was a disruption in service, how long would it take for the platform to become overcrowded? Based on the initial design concept, a total of (8,550 – 900 – 550 – 686), or 6,414 ft² of space is available for queuing passengers, while leaving circulation space available for arriving passengers. A typical minimum design value for passenger waiting

areas is 5 ft²/p, which allows passengers to wait without touching one another. At this level of crowding, 1,282 people could be accommodated on the platform. This is about 20% higher than the peak 15-minute entering demand. At a minimally tolerable crowding level of 3 ft²/p, about 2,138 people could be accommodated, representing about 73% of the p.m. peak-hour entering demand. However, most passengers would find this amount of crowding to be uncomfortable, and it is close to the design evacuation load of 2,215 people calculated in the previous example problem (note that this design load evacuation load includes 1,400 passengers requiring evacuation from trains). The transit agency should plan to limit platform access under either circumstance to limit the amount of crowding.

The Results

The initial design concept appears to produce a wider platform than required to accommodate either typical or non-typical conditions. Alternative designs could involve spreading out the exit points to narrow the platform; this would also have the benefit of shortening the distance to the nearest platform exit.

CALCULATION EXAMPLE 4: ESCALATOR QUEUING AREA

Derived from a problem in Fruin (2).

The Situation

A subway platform on an urban heavy rail line will be modified to install an up direction escalator at the center of a subway platform.

The Question

What is the pedestrian queuing and delay for the proposed installation?

The Facts

- Field counts of passengers discharged by the subway trains show that maximum traffic occurs during a short micro-peak, when two trains arrive within 2 min of each other, carrying 225 and 275 passengers, respectively.
- The remaining trains in the peak period are on 4-min headways.
- The platform is 900 ft (275 m) long, and 15 ft (4.6 m) wide.
- Field observations of other subway stations in this city with similar passenger volumes reveal a maximum escalator capacity of 100 p/min (for the assumed 120 ft/min [36.6 m/min], 40-in. [1-m]-wide escalators in this example), as opposed to the nominal capacity of 90 p/min given in Exhibit 10-31.

Computational Steps

Constructing the Time Clearance Diagram

- A graph is constructed (Exhibit 10-39) with time, in minutes, as the horizontal axis, and pedestrians as the vertical axis.
- The escalator capacity of 100 p/min is then drawn (dashed sloped line).
- The arrival rate at the escalator is a function of the train discharge time and walking time required to reach the escalator. If it is assumed that pedestrians

are discharged uniformly along the length of the platform and the escalator is located in the center of the platform, arrival time can be approximately represented on the clearance diagram by determining the time required to walk half the platform length. A commuter walking speed of 91.4 m/min (300 ft/min) is used in this example.

$$\text{Total arrival time} = \frac{1/2 \text{ platform length}}{\text{average walking speed}} = \frac{450 \text{ ft}}{300 \text{ ft/min}} = 1.5 \text{ min}$$

The two train arrivals, with 225 and 275 passengers, are plotted as solid lines on the diagram.

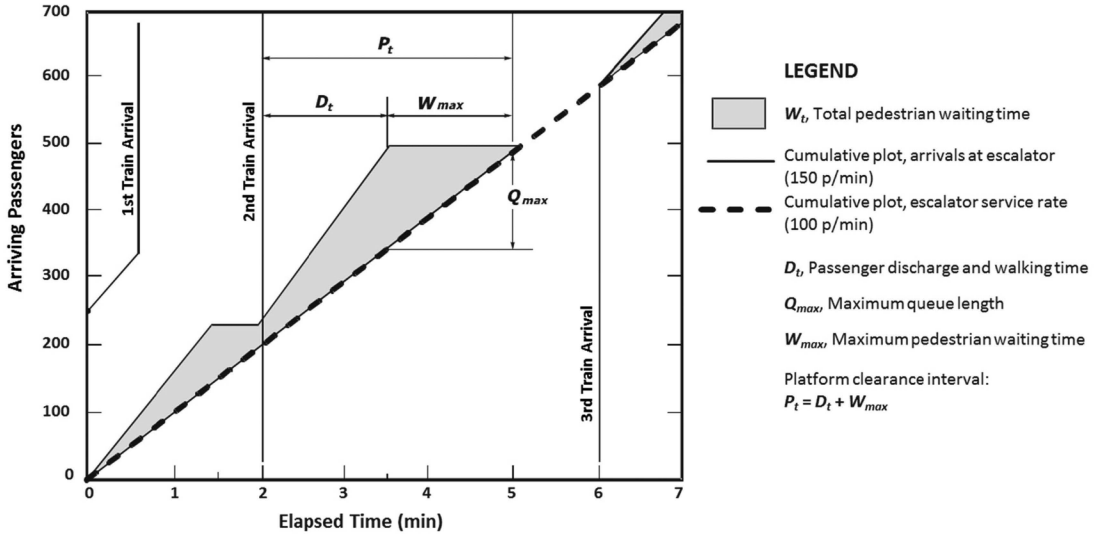


Exhibit 10-39
Calculation Example 4: Time Clearance Diagram

Determining the Maximum Queue Size and Maximum Wait

Assuming that all the passengers will use the escalator and not the stairs, the clearance diagram illustrates a number of significant facts. The shaded area between the pedestrian arrival rate (solid line), and the escalator service rate (dashed line), represents *total waiting time*.

Dividing the waiting time area by the number of arriving passengers gives *average passenger waiting time*. The maximum vertical intercept between these two lines represents *maximum passenger queue length*. The maximum horizontal intercept represents the *clearance interval* of the platform.

The clearance diagram shows that a maximum queue size of 75 persons would be generated by the first train arrival, if all persons seek escalator service. It also shows that 25 persons will still be waiting for the escalator service when the next train arrives.

The maximum waiting time for escalator service after the first train arrival is 1 min. The average passenger waiting time is 15 s. After the second train arrival, the maximum waiting and maximum queue size builds up to 1.5 min and 150 passengers, respectively. If it is assumed that passengers will divert to the stairs if the maximum escalator wait exceeds 1 min, a 1-min-wide horizontal intercept on the graph shows that maximum queue size will not likely get larger than 50 persons. This is about the limit observed for

low-rise escalators of this type, where alternative stationary stairs are conveniently available.

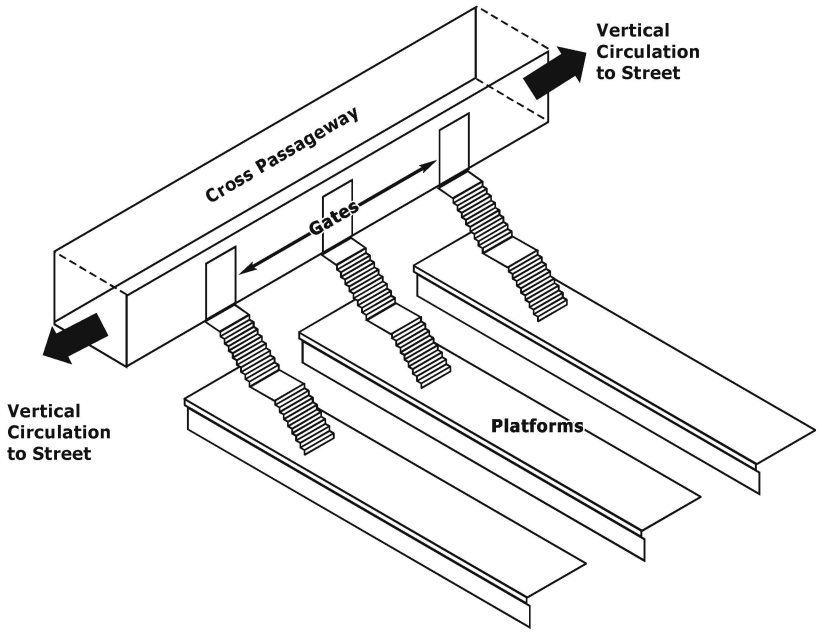
CALCULATION EXAMPLE 5: MULTIPLE PEDESTRIAN ACTIVITIES IN A FACILITY

Derived from an example in Benz (33).

The Situation

A new cross passageway (Exhibit 10-40) will provide access to and from the ends of platforms at a busy commuter rail terminal that currently has access at one end only. The passageway is essentially a wide corridor that will run perpendicular to and above the platforms, with stairs connecting the passageway to each platform. The cross passageway is connected to the surface at several points.

Exhibit 10-40
Calculation Example 5: Cross Passageway Layout



The Question

Can the corridor meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate?

The Facts

- Surveys at the station show that passengers departing on trains typically start to gather in front of a gate about 23 min before the train's scheduled departure time and assemble at the following rates:

Time Before Departure (min):	20	15	10	5	1
Departing Passengers (% gathered):	9	26	53	86	100

- The maximum accumulation of passengers outside the gate to the train platform occurs just before the opening of the gate—typically 10 min before train departure when 53% of the passengers leaving on the train are present. The

accumulation of waiting passengers, if large enough, can easily affect the cross passageway width available to handle longitudinal flow.

- As shown in Exhibit 10-41, the cross passage way is 140 ft long with an effective width of 25 ft (i.e., the width actually available for passenger activities: the wall-to-wall dimension minus the width occupied by obstructions and columns and the boundary or "cushion" maintained by pedestrians along walls). During the 1 min before the opening of the departure gate, 194 people will be waiting in the cross passageway. The flow rate of people walking along the corridor during this time is 167 p/min.

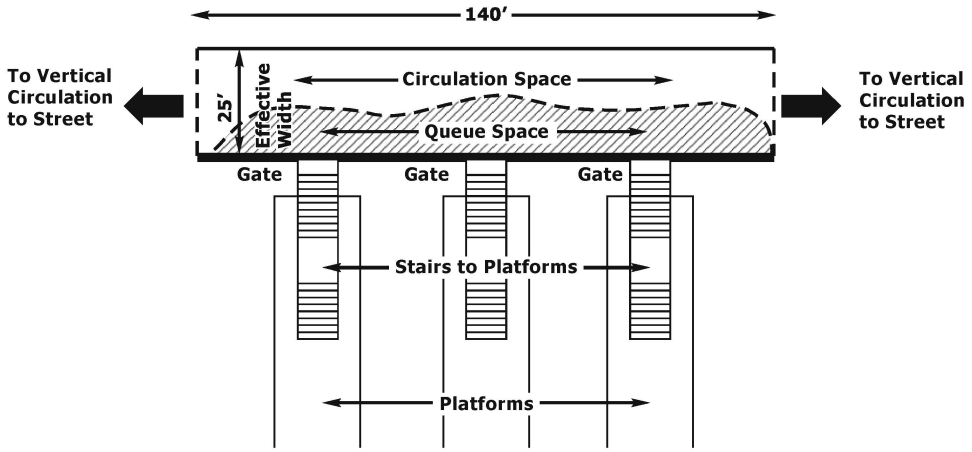


Exhibit 10-41
Calculation Example 5: Circulation and Queuing Spaces

Computational Steps

Outline of Solution

The problem is to examine whether the corridor can meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate. The analysis period is the 1 min before the opening of the gate when the maximum accumulation of waiting passengers will occur.

Determining the Size of the Queuing Space

With a design criterion of LOS B, the average pedestrian queuing area is 10 ft^2/ped (see Exhibit 10-32). This criterion reflects the unordered (random) nature of the queue in this space, the need for some circulation and movement within the queue, and the comfort level expected by commuter rail passengers who may be waiting for some time before the gate opens. The 194 people waiting will require:

$$194 \text{ p} \times 10 \text{ ft}^2/\text{p} = 1{,}940 \text{ ft}^2$$

The shape of the queue has to be estimated in order to determine the portion of the 25-ft-wide cross passageway that the queue will occupy. For this example, the waiting passengers, occupying 1,940 ft^2, are assumed to be evenly distributed along the 140-ft linear dimension of the space. Therefore, the queue is expected to require the following width at its widest point:

$$\frac{1{,}940\ \text{ft}^2}{140\ \text{ft}} = 13.9\ \text{ft}$$

This leaves 11.1 ft available for the flow of the 167 circulating passengers who would walk through the cross passageway during the 1-min peak queue period. The unit width flow rate available is:

$$\frac{167\ \text{p/min}}{11.1\ \text{ft}} = 15.0\ \text{p/ft/min}$$

The Results

From Exhibit 10-28, this identified pedestrian flow rate equates to LOS C to D. In this LOS range, walking speeds and passing abilities are becoming restricted but are generally considered adequate for peak-period conditions. There will be some conflicts between opposing pedestrian traffic streams.

CALCULATION EXAMPLE 6: COMPLEX MULTILEVEL STATION

Derived from a study of Town Hall Station in Sydney, Australia.

The Situation

A complex urban rail transit station currently experiences congestion during peak periods and is expected to witness significant ridership growth over the next 20 years. Various improvement and expansion schemes will be developed and tested to increase the capacity of the station and improve passenger comfort and convenience.

The Question

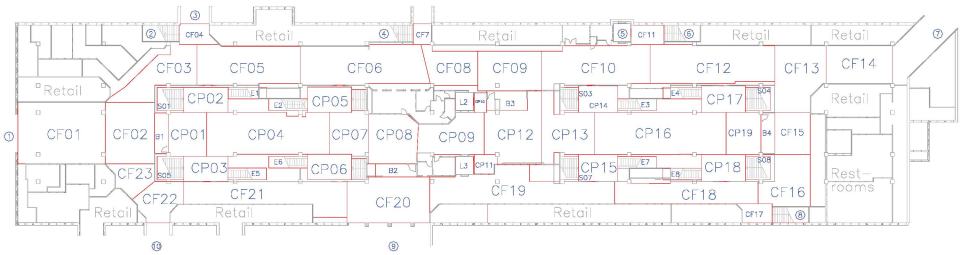
In order to identify potential improvements within the station, it is desirable to identify congested areas throughout the station, both on the platforms and on vertical circulation elements. Alternate station improvement and expansion schemes would then be laid out and tested in the same manner as the existing configuration.

The Facts

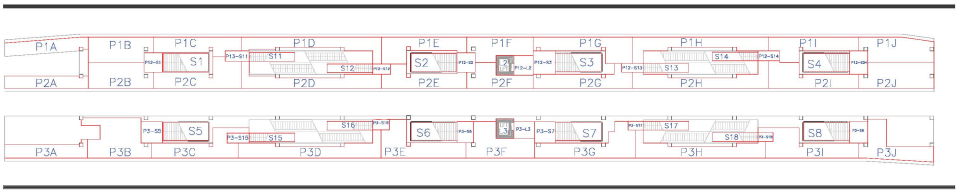
- The station has three levels underground: a concourse level and two platform levels that each have two platforms and three tracks. As shown in Exhibit 10-42, the concourse level includes a paid area surrounded by a free area lined with narrow retail establishments. The bottom image shows the upper platform level with vertical circulation passing through to reach the lower platform level. On each level one platform operates as an island serving two tracks and the other serves the third track.
- Because the station is an important transfer point, it experiences significant numbers of transfers, including same-track and cross-platform transfers, and transfers requiring changes between platforms and levels.
- Extensive surveys have been conducted to count the number of people passing through each entrance and using each vertical circulation element. Passenger interviews have been conducted to identify patterns of movement between platforms and the various access points and transfers within the station.

Exhibit 10-42
Calculation Example
6: Station Layout

Station Concourse



Upper Platform Level



Computational Steps

Outline of Solution

This example presents an approach based on traditional time-space analysis using a computer spreadsheet model to assess circulation. An alternate method using pedestrian simulation software is increasingly being applied to problems of this nature and is described in Example 7.

The station is subdivided into discrete circulation zones including areas of the concourse and platform levels and each of the vertical circulation elements. Zones and their identifying codes are shown in the concourse and platform plans in Exhibit 10-42. Extensive spreadsheets are used to assign peak-period pedestrians moving between distinct origin and destination points within the station to routes that either pass through or stay within each zone within the station. Additional spreadsheets organize data on the area of each zone, distinguish between persons walking and standing in each zone, and calculate levels of service in each zone.

Due to the extensive nature of this type of analysis, which is only practical with large spreadsheet models, this example presents the sequence of spreadsheets applied to the task without showing the lengthy equations, which, due to extensive cross-referencing of tables, are only meaningful in the spreadsheet environment.

Determining Pedestrian Volumes by Origin and Destination

The station has a total of 16 possible origins and destinations, comprising six platforms and ten external access/egress points. A pedestrian volume worksheet presents existing or future forecast volumes between any combination of the 16 origin–destination (O–D) points, including those who transfer from platform to platform and pedestrians who enter the free area of the concourse, but do not enter the station. Allowance is also made for those who may transfer to a different train on the same platform or enter and leave the concourse by the same door, as a person might do when visiting one of the shops on the concourse.

The data are input into the model in the form of a.m. and p.m. peak 5-min O–D matrices.

Assigning Pedestrian Routes

This worksheet includes an assignment by percent of people traveling between each of the 16 origins and destinations (256 combinations) to any of the 171 elements or zones (resulting in 43,776 assignment cells). Due to a change in direction of two escalators from the morning to the evening and different use of ticket gates at one entrance, different assignments are needed for each period. Additional modified routing assignment tables are required to analyze any proposed physical changes to the station.

Calculating Walk Volumes

This worksheet calculates the pedestrian volumes passing through each zone by multiplying the O–D volumes with the percentage assignment for each zone.

Calculating Walk Time

This worksheet includes the approximate time in seconds to walk through each analysis zone. Different walk times through a zone, representing different paths, can be associated to each origin and destination pair. The three typical choices are (*a*) the full length of the zone, (*b*) half the length, either as an average for people who end their walk in the zone or cut through it diagonally, or (*c*) a cross measurement that may be used for particular routes across some zones. Walk time is calculated based on distance in feet or meters divided by an assumed walking speed of 4.0 ft/s (1.2 m/s).

Calculating Percentage of Passengers Dwelling Within an Analysis Zone

This worksheet indicates the percent of pedestrians passing through a particular zone that dwell within that zone, either to wait for a train, to purchase a ticket, to make a purchase, or for other purposes. No dwell time is assumed on stairs, escalators, or fare control barriers but may be applied to the zones approaching these elements.

Calculating Dwell Time Within an Analysis Zone

This worksheet includes an average time in seconds that pedestrians who dwell in a zone spend there. On platforms, this time is related to train headways. On a system with very frequent service where people do not time their arrivals, this will generally be half the average headway. On a system with less-frequent service in which passengers time their arrivals to a train schedule, it will generally be less than half of the average headway. Appropriate times are also assigned for ticketing, browsing, or other dwell activities based on observations. A function based on volumes through circulation elements (e.g., turnstiles, stairs, escalators) representing crowding at the approach to these circulation elements may be added to this worksheet. The dwell time for the zones prior to the circulation elements, at the base of escalators and stairs, is based on a function related to the capacity of the element. When the circulation element approaches capacity, the dwell times in the prior zones are increased by the formula.

Determining Time–Space Demand

The demand for walk time–space is calculated for each analysis zone by multiplying pedestrian volumes in each zone by the walk time required and by an assumed design

standard of 1.4 m^2 per person. The demand for dwell time–space is calculated by multiplying pedestrian volumes in each zone by the dwell percent, the average dwell time, and an assumed dwell space of 0.65 m^2 per person. The two are totaled for a combined time–space demand in each zone.

Calculating LOS by Analysis Zone

The operating condition of each zone is assessed by levels of service. Design capacity for all elements is considered to be the threshold between LOS C and D. In order to calculate an LOS from a combination of walking and standing, the time–space demand is converted into a volume-to-*design* capacity ratio for each zone or element that is proportional to the LOS standards, as shown in the following table.

Level of Service	Volume-to-Design Capacity Ratios for Walk/Standing Zones	Volume-to-Design Capacity Ratios for Escalators/Fare Controls
LOS A	< 0.4	< 0.6
LOS B	0.4 – 0.6	0.6 – 0.8
LOS C	0.6 – 1.0	0.8 – 1.0
LOS D	1.0 – 1.5	1.0 – 1.1
LOS E	1.5 – 2.8	1.1 – 1.2
LOS F	2.8 +	1.2 +

Note: Ratios have no units and may be applied with any units of measure.

The Results

The product of this analysis is an LOS for each platform or mezzanine zone and each stairway, and a volume-to-capacity ratio for each fare control array and escalator. To provide a spatial representation of passenger congestion, station plans can be colored based on the rating for each zone using a geographic information system or other graphic software. By using a suitable range of colors to represent free-flow to congested conditions, the relative congestion of areas throughout the station can be observed.

CALCULATION EXAMPLE 7: APPLICATION OF PEDESTRIAN MICROSIMULATION SOFTWARE

Application of pedestrian simulation software to analyze passenger flow in a station.

Introduction

Pedestrian microsimulation software is increasingly being applied to passenger circulation studies for a wide range of transit facilities. Simple models can be developed relatively easily to study discrete areas within stations and more complex models can be developed to study passenger circulation in complete stations and complex multi-level intermodal stations.

The inputs required for a model vary depending on the type and extent of the area being analyzed and the outputs desired vary depending on the key issues of concern in a particular facility or part of a facility. Each of the available software programs also vary somewhat in the specific inputs, outputs, and terminology applied. This example, instead of looking at a specific situation and laying out calculations or specific parameters, describes in general terms the typical inputs, outputs, and considerations that go into developing a simulation model for any transit station facility.

Model Development Steps

Step 1: Collect and Format Data

When creating a model, the first elements required are some form of pedestrian flow data for the area and plans of that area. Data should be summarized to the appropriate timeframe of the simulation. In a simple model, the flow of pedestrians might be relatively uniform, but where data or operational circumstances dictate, volumes may be more variable. A common method of entering pedestrian volumes is an origin–destination matrix that corresponds to the model entry and exit locations. Pedestrian flow data can be entered in this fashion, for the time period desired by the type of pedestrian. From there, data can be refined down to the smallest time increment needed, allowing the data to be peaked as needed.

As with other types of modeling exercise, it is common practice to create a base year model first (where existing transit facilities exist), and to agree upon all relevant future year data assumptions and forecasts at the outset. In some cases, it may also be relevant to plan for the creation of a future year "do nothing" model scenario to allow the implications of a proposed project to be identified.

Step 2: Prepare CAD Plans

The layout of the area to be modeled is typically entered into the model in a standard format CAD plan drawing file. CAD plans from architects or engineers typically require editing before they are suitable for importing into pedestrian simulation software. At a minimum, a CAD layer showing only boundaries to movement is required; some linework in typical CAD files would be interpreted as barriers to movement by the pedestrian simulation software. Additional linework and other graphic elements may be required for clarity in outputs, but must be separated for use with the software. It is therefore helpful to edit the CAD files into two types of layers:

- Presentation CAD and
- Simulation CAD.

Presentation CAD layers provide useful contextual information about the pedestrian venue but they are not obstacles to movement; examples include:

- Text labels;
- Stair steps and landings;
- Escalator landings, comb lines, and work points;
- Door swing paths; and
- Overhead elements.

Presentation CAD can also provide useful reference points for laying out control objects in the pedestrian simulation software.

Simulation CAD lines represent objects that are genuine obstacles to pedestrians; examples include:

- Walls,
- Balustrades and railings,
- Faregates,

- Windows,
- Door jambs,
- Furniture, and
- Vehicles.

The more CAD lines that are retained for use in a simulation, the longer a simulation may take to run, so the simulation CAD layer should be the minimum CAD necessary to define the pedestrian-accessible space. When running a simulation, the presentation CAD can be kept aside, which may speed up the simulation time.

The simulation layer should also be flattened, to ensure that all lines truly intersect. Further, it should be examined for small gaps in the linework that define the boundaries of accessible space. Any gaps discovered should be closed to prevent models from assuming there is a means of passing the line.

Step 3: Model Building

To use the data created in Step 1 with the CAD plans created in Step 2, a simulation must have model objects created within it to inform simulated pedestrians what area they are passing through, and how those elements are linked to one another. In this step, vertical circulation elements need to be created if present, and their operations defined (i.e., escalator directionality, elevator speed, escalator incline). Model entry points have to be created and demand data associated with them. Model exits are created and linked to entries. Any special spatial objects and their controls need to be created (e.g., queues for ticket vending machines, waiting areas, directional controls, train announcements, and boarding calls if applicable). Once model elements have been created, validated, and checked, the simulation can be run.

Step 4: Model Calibration and Validation

Models generally need a series of debugging and calibrating runs to establish proper functioning and appropriate behavior. Some issues may be noticeable early in a simulation run, allowing the user to stop the run early and make corrections. Other issues may not be recognizable until a model has run through a significant portion of the simulation period. Once a model is running through its full timeframe without errors or inappropriate behaviors, full simulations may be run and variations assessed.

Validation of base year model flows against survey data is complicated when using simulation software that incorporates dynamic route assignment functionality, due to the absence of the types of statistical tests developed for the purpose of validating roadway models (e.g., the GEH test).

Step 5: Model Analysis

Analytical measures can be coded into the model as it is being developed to produce selected statistics, graphs, maps, or video clips. After successful model validation, these analytical measures can be recorded for subsequent model runs and variations on the design or operation. Most software programs can produce analyses for cordon counts, travel times, or area analyses and display those results in either graphical or video formats.

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APPENDIX A: EXHIBITS IN METRIC UNITS

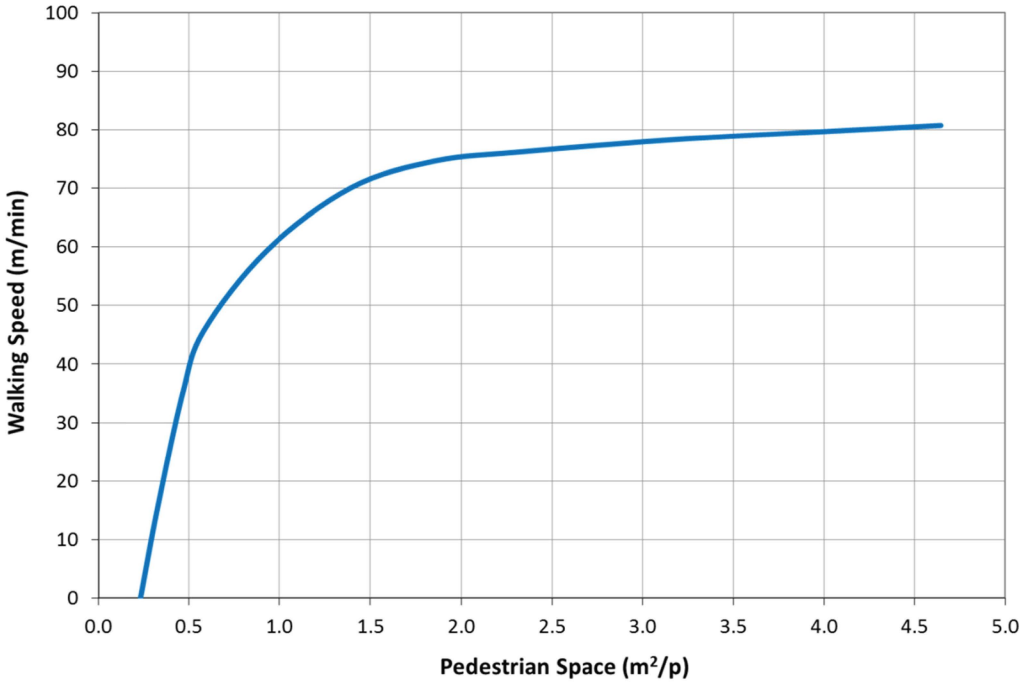


Exhibit 10-10m
Pedestrian Speed on Walkways

Source: Derived from Fruin (*2*).

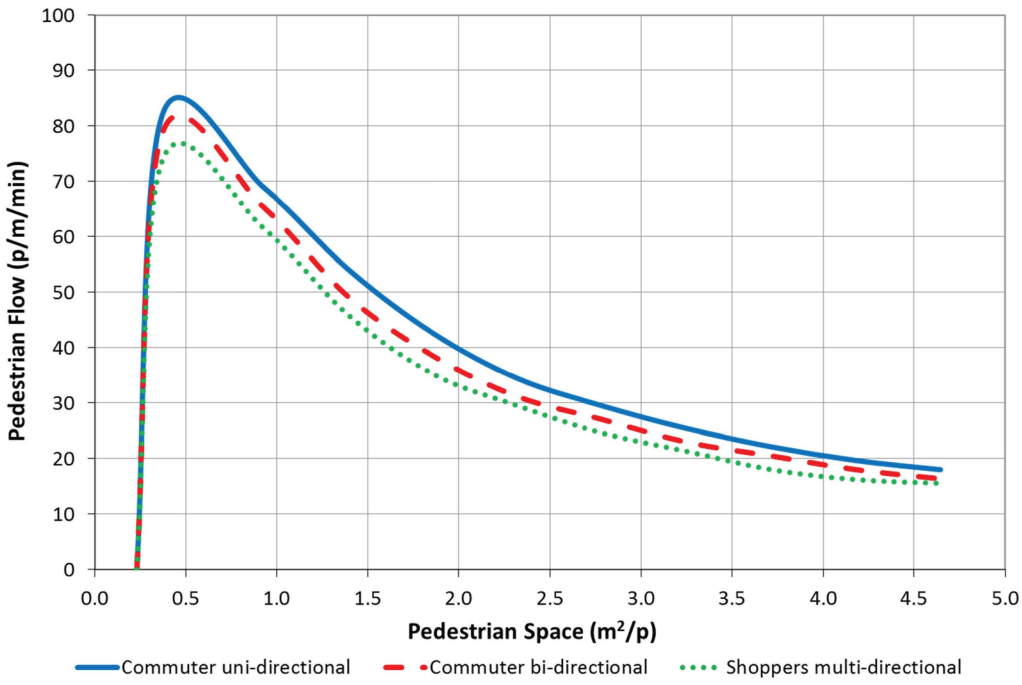
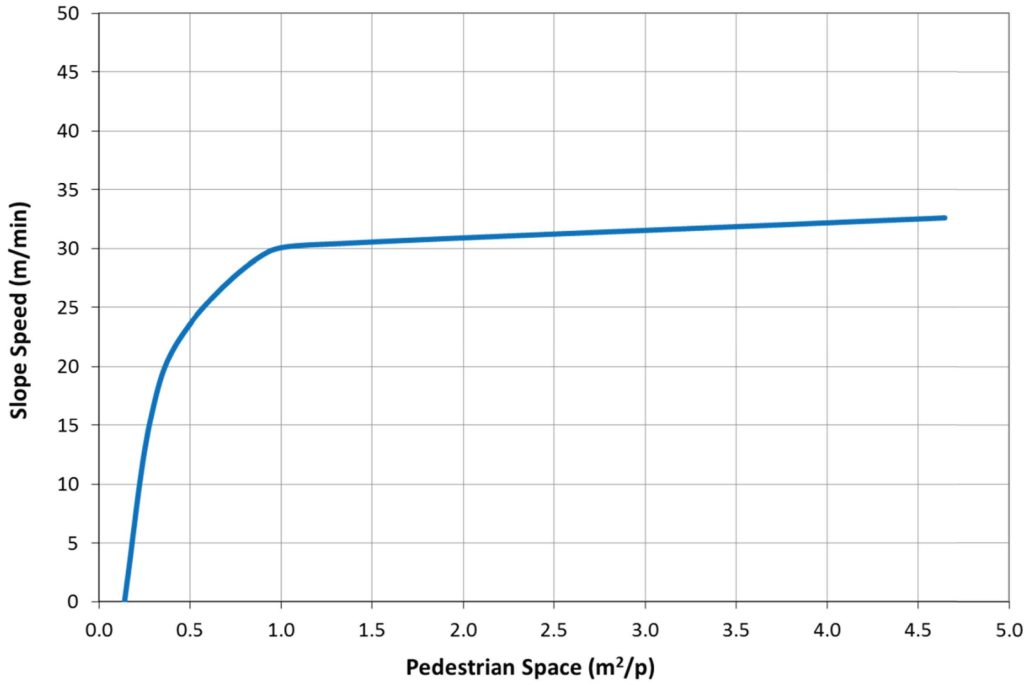


Exhibit 10-11m
Pedestrian Flow on Walkways by Unit Width and Space

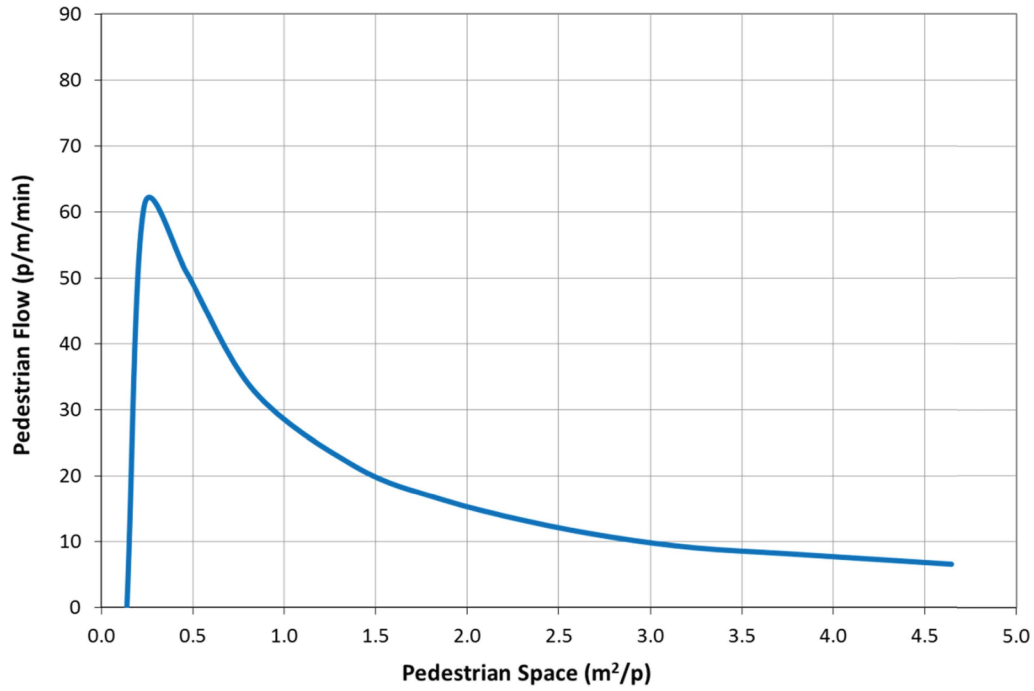
Source: Derived from Fruin (*2*).

Exhibit 10-15m
Pedestrian Ascent Speed on Stairs



Source: Derived from Fruin (*2*).

Exhibit 10-16m
Pedestrian Flow Volumes on Stairs



Source: Derived from Fruin (*2*).