PART 7
STOP, STATION, AND TERMINAL CAPACITY

CONTENTS

LIST OF EXHIBITS

CHAPTER 1. INTRODUCTION

Part 7 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents a discussion of the features and elements of transit stops, stations, and terminals and contains procedures for estimating the capacities of various elements of transit terminals.

- *Chapter 1* provides an introduction to the material presented in Part 7.
- *Chapter 2* is an overview of the different types of stops, stations, and terminals, including discussions of facility sizes and amenities.
- *Chapter 3* presents procedures for evaluating passenger circulation on walkways and stairways, and in queuing areas such as platforms. ADA and emergency evacuation needs are discussed.
- *Chapter 4* contains procedures for sizing passenger waiting areas at stops and stations and for providing passenger amenities within these areas. For bus and rail stations, procedures are provided for sizing outside transfer facilities, such as bus transfer, park-and-ride, and kiss-and-ride areas, as well as the various inside-terminal elements, such as walkways, stairways, escalators, elevators, turnstiles, ticket machines, and platforms.
- *Chapter 5* contains references for material presented in Part 7.
- *Chapter 6* presents example problems illustrating the sizing of stop, station, and terminal elements.
- *Appendix A* provides substitute exhibits in metric units for those Part 7 exhibits that use U.S. customary units.

Exhibits also appearing in Appendix A are indicated by a margin note such as this.

Although previous efforts have involved designing terminal facilities based on maximum pedestrian capacity, research has shown that a breakdown in pedestrian flow occurs when there is a dense crowding of pedestrians, causing restricted and uncomfortable movement. For this reason, many of the procedures contained in this chapter for sizing terminal elements are based on maintaining a desirable pedestrian level of service.

For 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 that assess the impact of queue spillback on downstream facilities can be used to size internal spaces within a terminal facility, and thus their application is discussed in this part of the TCQSM. For stations with frequent service, the time required to clear a station platform before the arrival of a following train or bus may be a critical consideration.

Design capacity is determined by peak conditions established by peak passenger discharge loads, peak waiting loads, extra loads due to “regular” service disruptions, and emergency evacuations. Specific requirements(R11) for addressing emergency evacuation contained in the National Fire Protection Association (NFPA) standard for fixed guideway transit and passenger rail stations (NFPA 130) are reviewed.

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. Specific requirements of The Americans with Disabilities Act of 1990 (ADA) pertinent to transit stations are discussed.

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CHAPTER 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 may display unique characteristics. The basic types of transit stops, stations, and terminals are presented in this chapter.

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, a bench or small shelter. Other bus stops are located on- or off-street in conjunction with transit centers, rail transit stations, or intermodal terminals.

On-street bus stops may be located on the near side of an intersection, the far side after the bus has passed through the intersection, or at a mid-block location. The choice of location is primarily related to the operational performance of the bus route and traffic, but can also be influenced by adjacent land uses and opportunities for easy transfers to crossing bus routes. For more discussion of bus stops as they relate to bus operations, refer to Part 4, *Bus Transit Capacity*.

Bus stop location factors.

There is ongoing debate about the operational advantages of near-side versus far-side placement. In general, a far-side placement will be most advantageous when buses operate in mixed traffic, while a near-side location will tend to be more feasible when buses operate in an exclusive lane. However, other factors such as signal priority for buses, location of an exclusive lane, and turning traffic patterns also factor into this choice. With a far-side stop location at signalized intersections, it is highly desirable to be able to pull buses into an adjacent parking lane or bus pullout so that traffic does not back up into the intersection. If such an area is not available, a near-side stop might be preferable. With a near-side location in mixed traffic, vehicles waiting for the signal prevent the bus from reaching its stop, and buses stopping to pick up or drop off passengers during a green phase block other traffic.

These factors tend not to apply when buses operate in an exclusive lane. Locating the stop on either the far or the near side in this situation results in a slower, safer operating speed through the intersection, which is particularly relevant for buses (or light rail vehicles) operating on an exclusive lane. A mid-block location may be called for when additional space is available or when a particular destination is located at mid-block. However, issues with pedestrian crossing safety may need to be addressed.

TRANSIT CENTERS

The term *transit center* is normally applied to facilities where multiple bus routes converge, offering transfers between lines. The term can also apply to intermodal stations that may combine local bus services with other transit services, intercity bus or rail, and associated services such as taxi stands, concessions, and ticket sales. Both types of facilities are normally located wholly or partially off-street and frequently include a more elaborate and extensive shelter and more passenger amenities than ordinary bus stops.

BUSWAY STATIONS

Busway stations are located along roadways dedicated for buses and are frequently larger and more elaborate than typical bus stops, but are shorter than most light rail stations. Like the busways they serve, these stations may be either off-street or on-street. The length of a busway 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 very limited, consisting of just a paved area and sign, or much more elaborate, with shelters, seating, ticket machines, and other amenities. 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.

TCRP Report 90, Volume 2,(R9) provides guidance on designing busway stations.

Busway stations usually consist of side platforms boarded from the right side of the bus, but some center platform stations are used with boarding from either the left or right side of the bus (this requires buses designed with doors on both sides). Center platforms can also be used when the bus lanes operate contraflow. Busway stations may have a single lane in each direction, or a passing lane can be provided at stations to increase operational capacity and allow for multiple services that skip some stations.

LIGHT RAIL 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, or on a transit mall. High and low platforms have 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. Fare collection on light rail systems is typically by the proof-of-payment system, so stations do not have fare gates or barriers.

HEAVY RAIL STATIONS

Stations on heavy rail, rapid transit, or metro systems are usually more elaborate than light rail or many commuter rail stations. Due to the presence of third-rail power in many of these systems, and to prevent passengers from entering the trackway, these stations always have high-level platforms. Stations are most often located underground or elevated, and frequently have intermediate mezzanine levels between the street and platform levels. Both center or 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. Most heavy rail stations have fare control arrays and enclosed paid zones, although some European systems use proof-of-payment systems.

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. These stations may use either center or side platforms or a combination of both in larger terminals. 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 for passenger equipment and thus can impact the placement of platform features such as wheelchair ramps. Platforms in these stations 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 if 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.

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 poses unique challenges for passenger access, especially where extreme height changes are experienced, potentially requiring long or steep ramps to reach the vessel.

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 automated guideway transit. Such facilities may have a variety of other services and connections, including parking, drop-off, ticket vending, and information booths, and may be integrated with retail shopping, services, and entertainment.

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CHAPTER 3. PASSENGER CIRCULATION AND LEVEL OF SERVICE

PEDESTRIAN CIRCULATION CONCEPTS

An important objective of a transit stop or station is to provide adequate space and appropriate facilities to accommodate projected peak pedestrian demands while ensuring pedestrian safety and convenience. Early efforts involved designing transit stations based on maximum pedestrian capacity without consideration of pedestrian comfort and convenience. Research has shown, however, that capacity is reached when there is a dense crowding of pedestrians, causing restricted and uncomfortable movement.(R6)

The procedures for estimating capacity presented in this section are based on a relative scale of pedestrian comfort and convenience. Procedures for evaluating pedestrian capacity and level of service (LOS) are contained in Fruin's *Pedestrian Planning and Design*.(R6) Procedures for analyzing pedestrian circulation on sidewalks, street corners, and crosswalks are presented in the 2000 *Highway Capacity Manual* (HCM).(R8)

Procedures in this chapter are based on providing a suitable passenger LOS rather than designing for maximum capacity.

Pedestrian Capacity Terminology

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 or as persons per unit of time. Both a maximum 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 second.
- *Pedestrian flow rate*: number of pedestrians passing a point per unit of time, expressed as persons per minute, 15 minutes, 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 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*: average area used by or provided for each pedestrian in a walkway or queuing area, expressed in terms of square feet or meters per pedestrian; this is the inverse of density, but is a more practical unit for the analysis of pedestrian facilities. 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, queuing, conversing, shopping, etc.) multiplied by the time spent doing the activity within a specific area.
- *Effective width or area*: the portion of a walkway or stairway's width or the area of a space that is normally used by pedestrians. Areas occupied by physical obstructions and buffer spaces adjacent to walls and obstructions are excluded from effective width or area.

Principles of Pedestrian Flow

The relationship between density, speed, and flow for pedestrians is described in the following formula:

Equation 7-1

$$v = S \times D$$

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/ft^2, p/m^2).

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

Equation 7-2

$$v = S / M$$

where:

v = pedestrian flow per unit width (p/ft/min, p/m/min);
S = pedestrian speed (ft/min, m/min); and
M = pedestrian space (ft^2/p, m^2/p), adjusted as appropriate for pedestrian characteristics.

Refer to Exhibits 3-25 or 5-22 for data on the space occupied by pedestrians.

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 queuing areas are based on available standing space, perceived comfort and safety, and the ability to maneuver from one location to another. Since pedestrian LOS is based on the amount of pedestrian space available, the LOS thresholds can be used to specify desirable design features such as platform size, number and width of stairs, corridor width, and so forth.

CIRCULATION ON WALKWAYS

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

- pedestrian walking speed;
- pedestrian traffic density;
- pedestrian characteristics, bikes or strollers present, and 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).

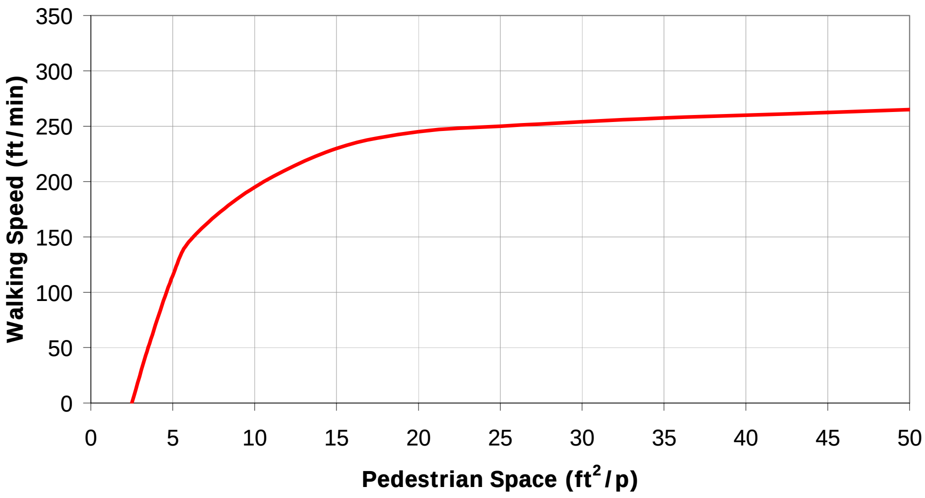
Density

Density is the most significant factor influencing pedestrian walking speed.

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 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.

Exhibit 7-1 shows the relationship between walking speeds and average pedestrian space (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 7-1
Pedestrian Speed on Walkways[R6]



An alternative figure using metric units appears in Appendix A.

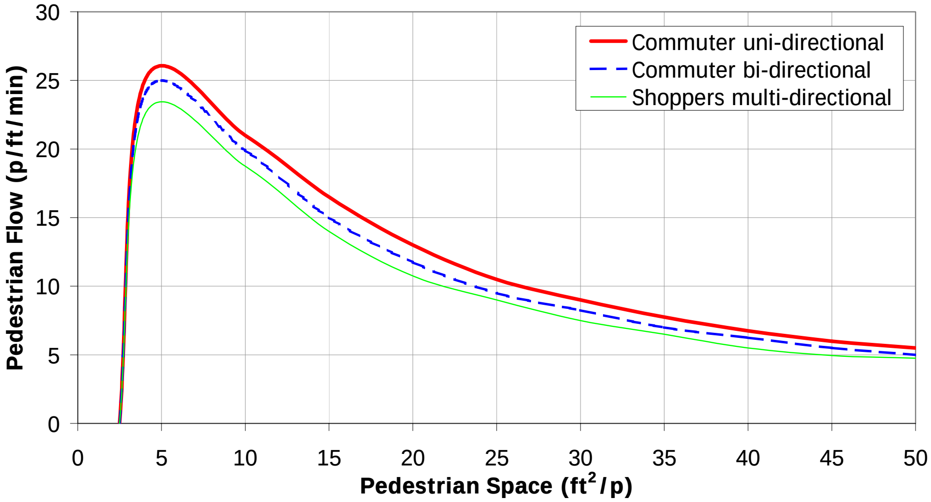
Effective Walkway Width

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 walls and platform edges and 12 in. (0.3 m) should be deducted next to other obstructions, including walls up to about 3 feet (1 m) tall.

Exhibit 7-2 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.

Exhibit 7-2
Pedestrian Flow on Walkways by Unit Width and Space(R6)



An alternative figure using metric units appears in Appendix A.

As shown in Exhibit 7-2, 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 ft^2 (0.5 m^2) 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. Instead, the LOS approach should be used for designing pedestrian spaces.

Levels of Service for Walkways

Exhibit 7-3 lists the criteria 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. Graphical illustrations and descriptions of walkway levels of service are shown in Exhibit 7-4. Capacity is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS "E."

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

Note that the LOS thresholds shown here differ from those shown in the HCM2000. Thresholds shown in the HCM2000 are intended primarily for sidewalks and street corners, while those shown here are typically used for transit facilities, whether on-street or off.

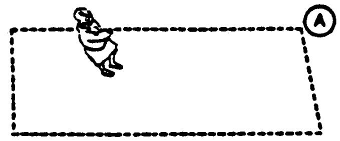
Exhibit 7-3
Pedestrian Level of Service on Walkways(R6)

		Expected Flows and Speeds		
LOS	**Pedestrian Space (ft^2/p)**	**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*

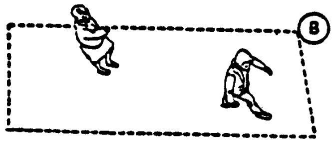
		Expected Flows and Speeds		
LOS	**Pedestrian Space (m^2/p)**	**Avg. Speed, *S* (m/min)**	**Flow per Unit Width, *v* (p/m/min)**	***v/c***
A	≥ 3.3	79	0-23	0.0-0.3
B	2.3-3.3	76	23-33	0.3-0.4
C	1.4-2.3	73	33-49	0.4-0.6
D	0.9-1.4	69	49-66	0.6-0.8
E	0.5-0.9	46	66-82	0.8-1.0
F	< 0.5	< 46	*Variable*	*Variable*

v/c = volume-to-capacity ratio

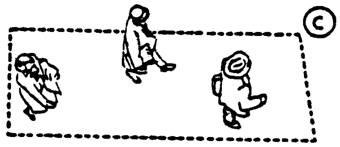
Exhibit 7-4
Illustration of Walkway Levels of Service(R6)



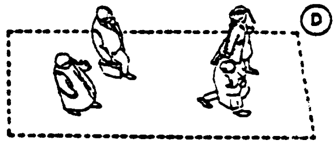
LEVEL OF SERVICE A
Walking speeds freely selected; conflicts with other pedestrians unlikely.



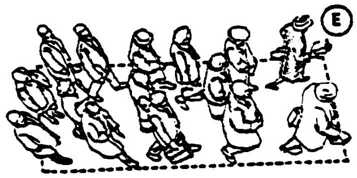
LEVEL OF SERVICE B
Walking speeds freely selected; pedestrians respond to presence of others.



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.

CIRCULATION ON STAIRWAYS

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

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 width of a stairway determines both the number of distinct lines of people who can traverse the stair and the side-to-side spacing between people, affecting 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).

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 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.

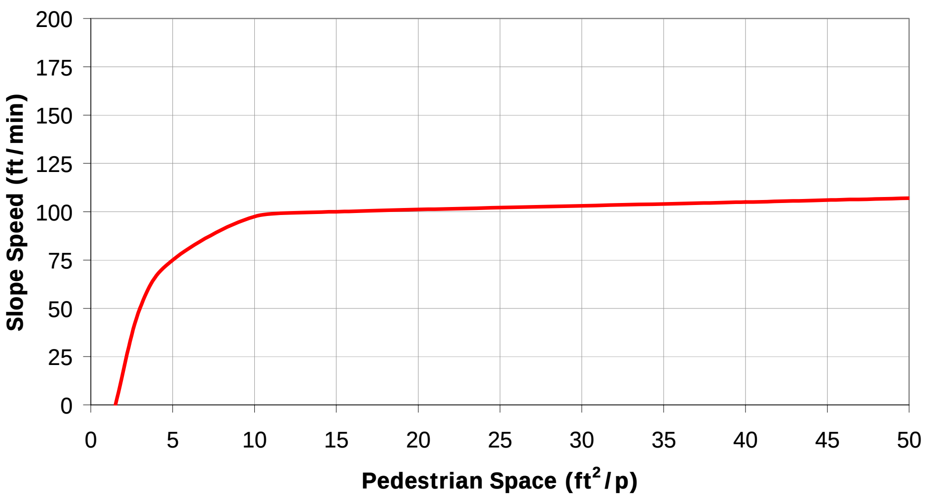
Because pedestrians are required to exert a higher amount of energy to ascend stairs as compared with descending stairs, lower flow rates typically occur in the ascending direction. For this reason, when stairs serve both directions simultaneously or when the same stair will be used primarily in the up direction during some time periods and primarily in the down direction during other time periods, the lower up 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. 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 longer stairs because pedestrians slow as they reach 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 (as opposed to measuring along the incline), 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 7-5 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.

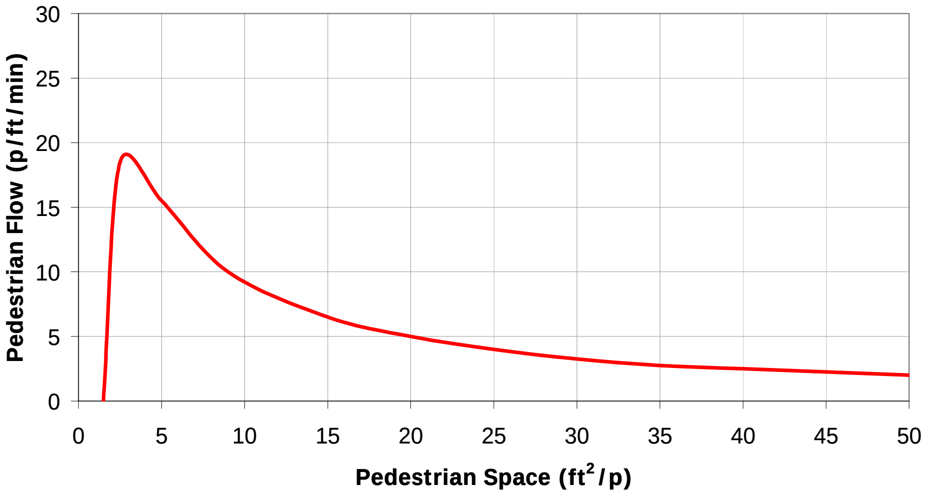
Exhibit 7-6 illustrates the relationship between flow rate on stairs in the ascending direction and pedestrians' space. As observed in this exhibit, the maximum ascending flow rate occurs at a pedestrian space of approximately 3 ft^2/p (0.3 m^2/p). For this lower pedestrian space, ascending speeds are 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 7-5
Pedestrian Ascent Speed on Stairs(R6)



An alternative figure using metric units appears in Appendix A.

Exhibit 7-6
Pedestrian Flow Volumes on Stairs(R6)



An alternative figure using metric units appears in Appendix A.

Pedestrian queuing can also 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 station facilities, with potential effects on pedestrian safety.

Levels of Service for Stairways

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 7-7 summarizes the LOS criteria for stairways. The threshold from LOS "E" to "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 HCM2000; the thresholds given in Exhibit 7-7 are ones typically used for transit facilities.

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

Exhibit 7-7
Level of Service Criteria for Stairways[R6]

LOS	Avg. Ped. Space (ft²/p)	Avg. Ped. Space (m²/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.

OCCUPANCY IN QUEUING AND WAITING AREAS

For queuing and waiting areas, the primary measure for defining LOS is the average space available to each person. In addition to the feeling of comfort provided by desired spacing, there is a also a direct relationship between the average space available to each person and the degree of mobility allowed. In dense standing crowds, there is little room to move, but limited circulation is possible as the average space per pedestrian increases.

Levels of Service for Queuing and Waiting Areas

Passenger waiting area LOS concepts are comparable with the street corner queuing concepts presented in the *Highway Capacity Manual.*

Levels of service for passenger queuing and waiting areas are shown in Exhibit 7-8. 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).

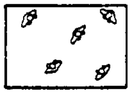
The LOS required for waiting within a facility is a function of the amount of time spent waiting, the number of people waiting, and a desired level of comfort. Typically, the longer the wait, the greater the space per person required. A person's tolerance of a level of crowding will vary with time. People will accept being tightly packed on an elevator for 30 seconds, but not in a waiting area for 15 minutes.[R8]

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.[R8]

Exhibit 7-8
Levels of Service for Queuing Areas[R8]

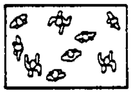
LOS	Average Pedestrian Area (ft²/p)	Average Pedestrian Area (m²/p)	Average Inter-Person Spacing (ft)	Average Inter-Person Spacing (m)
A	≥ 13	≥ 1.2	≥ 4.0	≥ 1.2
B	10-13	0.9-1.2	3.5-4.0	1.1-1.2
C	7-10	0.7-0.9	3.0-3.5	0.9-1.1
D	3-7	0.3-0.7	2.0-3.0	0.6-0.9
E	2-3	0.2-0.3	<2.0	<0.6
F	< 2	< 0.2	*Variable*	*Variable*

Exhibit 7-9
Illustration of Queuing Area Level of Service[R8]

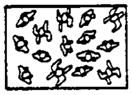


LEVEL OF SERVICE A
Standing and free circulation through the queuing area possible without disturbing others within the queue.

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

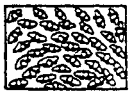


LEVEL OF SERVICE C
Standing and restricted circulation through the queuing area by disturbing others is possible; this density is within the range of personal comfort.



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.

MULTI-ACTIVITY PASSENGER CIRCULATION AREAS

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

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 7-10
Examples of Multiple Pedestrian Activities Within a Transit Station

(a) Grand Central Terminal (New York)

(b) Victoria Station (London)

In such cases, the method of pedestrian analysis is referred to as time-space analysis.(R3) 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.

The space required for a particular activity is represented by the formula:

Equation 7-3

$$TS_{req} = \Sigma\, P_i \times S_i \times T_i$$

where:

TS_{req} = time-space required (ft²-s, m²-s);
P_i = number of people involved in activity i;
S_i = space required for activity i (ft², m²); 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:

Equation 7-4

$$TS_{avail} = S_{avail} \times T_{avail}$$

where:

TS_{avail} = time-space available (ft^2-s, m^2-s);

S_{avail} = space available within the area analyzed (ft^2, m^2); 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 simulation models for pedestrian circulation are under development, but to date have generally involved significant manual input or have been limited in their ability to represent the complex multi-directional movements of pedestrians. Two approaches are possible. In the first, pedestrians are assigned to discrete pedestrian spaces through which they would pass, as defined by the analyst. A time-space analysis is then performed for each discrete space based on the number of pedestrians passing through and their activities within each space. The second approach utilizes micro-simulation methods to follow the movements of individual pedestrians and analyzes congestion and queuing. The latter approach has been developed for evacuation analyses, where pedestrians have a single purpose, but has not yet been successfully applied to general circulation.

ACCESS FOR PERSONS WITH DISABILITIES

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

Specific regulations relating to transit stations, including provision of accessible routes, appropriate architectural features, and accessible communications elements and features are contained in the Architectural Barriers Act of 1999(R1).

Rather than being an afterthought or an add-on in the planning of a transit station, these issues should be addressed at each stage of the planning and design process. For example, opportunities may be found to incorporate ramps into the design that serve passengers with disabilities, but that also serve movement by other passengers. Elements addressing the needs of persons with disabilities can be worked into a facility's overall aesthetic design.

EMERGENCY EVACUATION

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.

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

The key provisions of NFPA 130 (2000 edition) related to station capacity are summarized as follows:(R11)

1. Sufficient exit capacity shall be provided to evacuate station occupants (including those on trains) from platforms in 4.0 min or less.
2. 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.
3. A second means of egress at least 44 in. (1.12 m) wide and remote from the major egress route shall be provided from each platform.
4. The maximum distance to an exit from any point on a platform shall be not more than 300 ft (91.4 m).
5. Escalators shall not provide more than half of the exit capacity from any level and one escalator, resulting in the most adverse exiting condition, shall be assumed to be out of service and unavailable for egress.

Consult the current edition of NFPA 130 for more detailed information on the evacuation standards and calculation procedures. In particular, note that 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 Part 7 of the TCQSM for designing for daily passenger circulation.

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

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 must be provided, 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 where 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 multi-level 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 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. Although not specified in NFPA 130, some consideration should 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 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 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. *TCRP Synthesis 21*(R13) provides summaries of strategies that transit agencies have used effectively to reduce crime and/or improve passengers' perceptions of security.

Acts of violence on transit property have increased worldwide since the 1980s. *TCRP Synthesis 27*(R4) provides information on practices of transit agencies to prevent and respond to these acts. The FTA's Office of Safety and Security can provide additional information developed in the wake of the 2001 World Trade Center attack.

http://transit-safety.volpe.dot.gov/

CLARITY OF STATION LAYOUT AND WAYFINDING

In more complex transit stations and terminals, the 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

- Open ceilings and glass walls can provide visual connections to other levels and between points inside and outside the station;
- Alternate materials and colors 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.

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 7-11 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 7-12 shows possible elements and components to be considered in a system diagram for the evaluation of pedestrian flows at a transit station.

Exhibit 7-11
Sample Pedestrian Flow Diagram Through a Transit Terminal(R5)

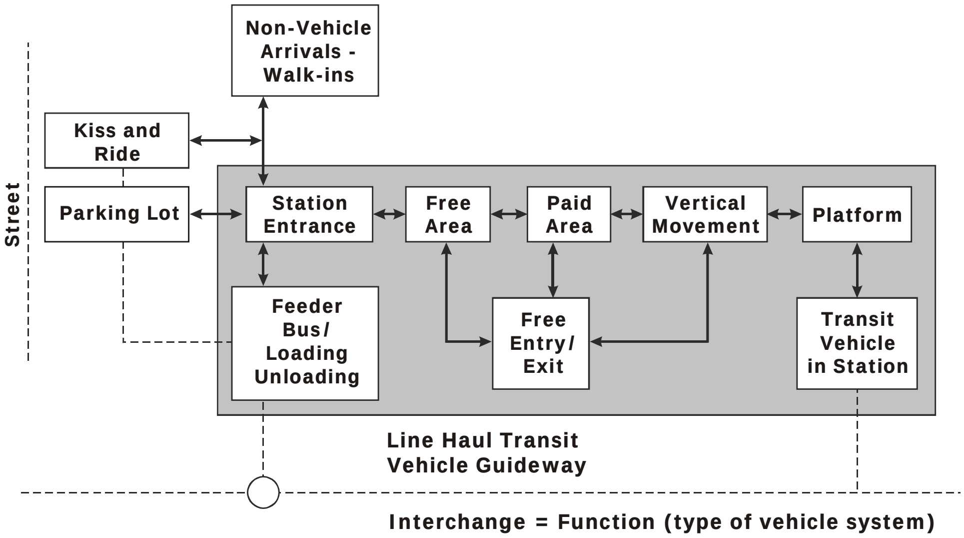


Exhibit 7-12
Elements of Passenger Circulation in a Transit Station(R6)

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, with varying degrees of manual input, can assist in the evaluation of alternate transit station designs as to their ability to effectively process transit passengers within certain LOS parameters.

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

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:

Equation 7-5

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

or

Equation 7-6

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

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%.

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.(R7) 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: (1) type—walkway, ramp, stairway, escalator, or elevator; (2) movements allowed—one-way or two-way (shared or not shared); (3) length—in feet or meters; and (4) 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, 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 minutes 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

In order 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 minutes).

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, 1.5 ft (0.5 m) is typically subtracted. A buffer of 2 ft (0.6 m) is typically subtracted for obstructions placed in corridors, such as trashcans and lockers. A buffer of 1 ft (0.3 m) is typically subtracted for walls in stairwells because transit users on the outside often use handrails. Finally, 3 ft (1 m) is typically subtracted to compensate for two-way movements on stairs.

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 7-3 for walkways, Exhibit 7-7 for stairways, and Exhibit 7-20 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 it may be of short or long duration.

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 wait time is half the bus or train headway.

Step 9: Add Travel Time Components and Assess Overall Level of Service

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. This can then be translated into an overall passenger processing LOS.

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CHAPTER 4. STATION ELEMENTS AND THEIR CAPACITIES

ON-STREET BUS STOPS

Design Factors

On-street bus stops typically share sidewalk space with other activities. The objective of analyzing the area needed or available for a bus stop is to provide adequate space both for those who are waiting for a bus and for those who are passing by. The recommended procedures for computing the size of passenger waiting areas is based on maintaining a desirable LOS. Depending on passenger volumes and available space, a bus stop may be as simple as a signpost along a sidewalk of minimal width, or more complex, with a larger paved area with a shelter and other amenities.

Waiting Area Level of Service

Passenger waiting area LOS utilizes concepts from the *Highway Capacity Manual.*

Levels of service for passenger waiting areas applicable to bus stops are shown in Exhibit 7-8. The LOS desired for waiting at a bus stop is a function of the amount of time spent waiting, the number of people waiting, and the surrounding conditions. Typically, the longer the wait, the greater the space per person required. Also, the required space per person may vary over time. For example, those waiting in the beginning will want a certain amount of space initially, but will be willing to accept less space as additional people arrive.(R8)

A person's acceptance of interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, a small number of passengers at a sidewalk bus stop may spread out more than a larger number that form an ordered queue at an urban bus stop.

The presence of passengers who use wheelchairs, strollers, or bicycles, or carry large luggage or packages should be assessed and suitable provision made in station space. Studies have shown that pedestrians keep as much as an 18-in. (0.5-m) buffer between themselves and the edge of a street curb. This suggests that the effective width of a bus stop should be computed as the total width minus 18 in. (0.5 m).

Evaluation Procedures

Determining Required Passenger Waiting Area

As discussed above, the procedures to determine passenger waiting areas at bus stops are based on maintaining a desirable pedestrian LOS. For most bus stops, the design LOS should be "C" to "D" or better. The following is a list of steps recommended for determining the desired bus stop size:

1. Based on the desired LOS, choose the average passenger space from Exhibit 7-8.
2. Estimate the maximum demand of passengers waiting for a bus at a given time.
3. Calculate the effective waiting area required by multiplying the average passenger space by the maximum passenger demand.
4. Calculate the total required waiting area by adding an 18-in. (0.5-m) buffer width (next to the roadway) to the effective waiting area.

OFF-STREET BUS STOPS

Design Factors

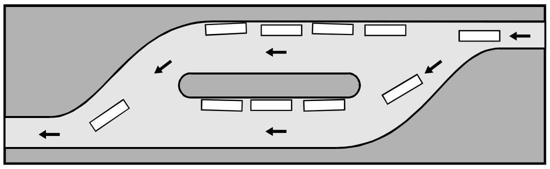
Larger bus stops, serving multiple bus routes, are often located off-street. They may be part of an all-bus transit center or may be provided in conjunction with a rail transit station, providing transfer to and from the rail service. For small transit stations, the number of loading areas (berths) is small, with a fairly simple access and layout configuration. For larger terminals, numerous berths and more sophisticated designs are applied. The Transbay Bus Terminal in San Francisco, for example, has 37 berths (not all currently used), serving 20,000 peak-hour passengers, while the Port Authority Bus Terminal in New York has 210 gates serving 200,000 passengers on a typical weekday.

Exhibit 7-13 illustrates various loading area arrangements. Four types of bus berths are typically applied: linear, sawtooth, angled, and drive-through.

Exhibit 7-13
Bus Loading Area (Berth) Designs and Examples

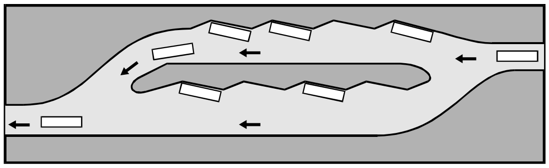
(a) Linear

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).



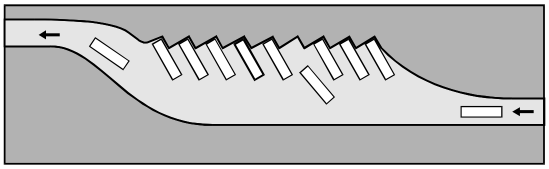
(b) Sawtooth

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



(c) Angled

Angled 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).



(d) 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).

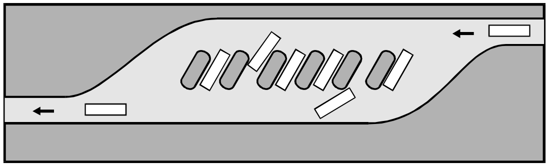


Photo locations:
(a) Newport, Rhode Island
(b) Olympia, Washington
(c) Newark Airport, New Jersey
(d) Vail, Colorado

Linear berths can operate in series and have capacity characteristics similar to on-street bus stops. Angled berths are limited to one bus per berth, and they require buses to back out. Drive-through berths can accommodate multiple vehicles. Shallow "sawtooth" berths are popular in urban transit centers and are designed to permit independent movements into and out of each berth. Individual berths may serve only one bus route, especially where service on the route is frequent, or they may serve more than one route where frequencies on each route are long enough to avoid conflict at the bus stop.

Example Problem 1 illustrates limiting the number of routes using a single berth.

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.(R12)

Waiting Area Level of Service

Levels of service for passenger waiting areas at off-street bus stops are the same as those for on-street bus stops (see Exhibit 7-8). However, because off-street facilities are larger and more complex, they incorporate spaces for pedestrian circulation that may be analyzed using the walkway thresholds presented in Exhibit 7-3.

Evaluation Procedures

The bus stop capacity procedures given in Part 4 are only applicable for relatively low bus dwell times (3 minutes or less). These procedures are applicable to off-street stops in the case of through-routed buses that do not layover at the stop, and for buses that coordinate their arrival times with certain train or express bus arrivals. When applying Equation 4-7, a g/C ratio of 1.00 is applicable when no traffic signals prevent buses from pulling into or out of the off-street facility. In addition, the minimum 10-second clearance time is applicable, representing the minimum time required for a bus to accelerate out of and clear the loading area, and for the next bus to pull in. Exhibit 7-14 identifies the estimated maximum loading area (berth) capacity under this condition.

Exhibit 7-14
Maximum Capacity of Off-Street Bus Berths Under Low Dwell Time Conditions

Dwell Time (s)	Berth Capacity (bus/h)
15	116
30	69
45	49
60	38
75	31
90	26
105	23
120	20
180	14

NOTE: Assumes 10-second clearance time, 25% failure rate, 60% coefficient of variation, and g/C ratio of 1.0. For multiple linear berths, multiply the above values by the number of equivalent berths, from Exhibit 4-14. For multiple sawtooth or drive-through berths, multiply the above values by the number of berths.

Note that these are maximum capacities based on a 25% failure rate. Lower failure rates may be desirable to provide better schedule reliability, resulting in lower capacities.

For larger bus stations, and for bus routes laying over or terminating at a station, the typical design practice is to provide for individual berths for each route direction. In these cases, Exhibit 7-14 does not apply, and the number of berths required will be the sum of the number of routes terminating at the station, plus twice the number of routes passing through the station (in order to provide separate berths for each direction).

STATION PLATFORMS

Design Factors

Transit platforms function as 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 7-15 illustrates typical side and center platform configurations at stations.

Exhibit 7-15
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 persons 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 clear width along a platform edge must be 60 in. (1,525 mm).

Similarly, NFPA 130 does not directly affect overall platform area unless obstacles require additional platform width to provide egress capacity past the obstacle, such as a stairway.(R11) The standard does specify, however, that egress routes must be at least 5 feet 8 in. (1.73 m) wide. When such a route passes between the edge of a platform and an obstacle, such as a stairway, an additional width of 1 foot 6 in. (457.2 mm) must be provided at the platform edge and 1 foot (304.8 mm) must be provided next to the obstruction, so that a minimum clear width of 8 feet 2 in. (2.5 m) is required in such a case.

Waiting Area Level of Service

Queuing area levels of service for transit platforms are the same as for bus stop waiting areas, and are defined in Exhibit 7-8. The LOS thresholds are based on average space per person, personal comfort, and degrees of internal mobility. 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.

Evaluation Procedures

The shape and configuration of a platform is dictated by many system-wide 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:(R3)

- 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 7-16 illustrates the use of these areas for a transit platform serving buses.

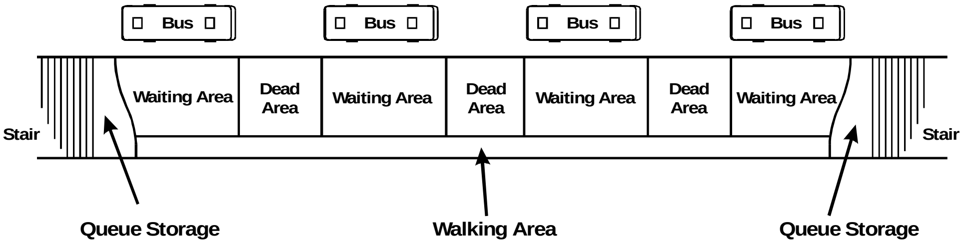


Exhibit 7-16
Transit Platform Areas(R3)

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 terminal. Dead areas should be taken into consideration when choosing the size and configuration of a platform.

Platform Sizing

The procedures to determine the size of a transit platform are based on maintaining a desirable pedestrian LOS. For transit platforms, the design LOS should be "C" to "D" or better. The following is a list of steps recommended for determining the desired platform size:

1. Based on the desired LOS, choose the average pedestrian space from Exhibit 7-8;
2. Adjust as appropriate for passenger characteristics;
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 by using the appropriate procedures for walkways described previously;
6. Calculate the queue storage space required for exit points (at stairs, escalators, and elevators) by using the appropriate procedures described in the following sections;

7. Consider the additional platform space that will be unused, including dead areas and physical obstructions;
8. Add a 3-ft (1-m) buffer zone (18 in., or 0.5 m, on each side) to the width of the platform; and
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.

SHELTERS, WAITING ROOMS, AND SEATING

Design Factors

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.

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 to 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.

Shelter or Waiting Room 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 7-8. 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 7-8. 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 Equations 7-3 and 7-4 can be applied. A simpler analysis could be conducted using a space per pedestrian that is between the walking criteria shown in Exhibit 7-3 and the queuing criteria presented in Exhibit 7-8.

The desirable number of seats is a question of the maximum number of people who would choose to sit 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.

WALKWAYS

Design Factors

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

- Pedestrian walking speed,
- Pedestrian traffic density, and
- Walkway width.

It is not desirable to design walkways based on total capacity, but on a desired pedestrian LOS. The desirable pedestrian environment allows sufficient space for the pedestrian to

- Walk at a preferred speed,
- Bypass slower pedestrians,
- Avoid conflicts with oncoming or crossing pedestrians, and
- Interact visually with surroundings.

For daily circulation, design walkways based on a desired pedestrian level of service, not capacity.

The levels of service given in Exhibit 7-3 provide a relative scale for achieving this desirable pedestrian environment.

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-minute peak period is usually recommended. However, because micro-peaks (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. Micro-peaking 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.

Evaluation Procedures

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 7-3 lists the criteria for pedestrian LOS on 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 is a list of steps recommended for determining the required walkway width:

Refer to Exhibits 3-25 or 5-22 for data on the space occupied by pedestrians.

1. Based on the desired LOS, choose the maximum pedestrian flow rate (p/ft/min or p/m/min) from Exhibit 7-3.
2. Estimate the peak 15-minute pedestrian demand for the walkway.
3. Multiply by an appropriate adjustment factor to account for pedestrians who use additional space, such as wheelchair users and those transporting large items. Consideration should also be given for pedestrians who use service animals.
4. Compute the design pedestrian flow (p/min) by dividing the 15-minute demand by 15.
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 3 ft (1 m), with an 18-in. (0.5-m) buffer on each side to the effective width of walkway.

Determining Walkway Capacity

The 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 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. Adjust for special pedestrian characteristics, as appropriate.
4. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

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 2000 edition, these values were a pedestrian flow rate of 2.27 p/in/min (27.2 p/ft/min, or 89.3 p/m/min), and a travel speed of 200 ft/min (61 m/min).(R11) The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

DOORWAYS

Design Factors

Doorways or constrictions in the width of a walkway 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.

http://www.access-board.gov/adaag/html/adaag.htm

The effect of doorways on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a doorway, there must be sufficient time-headway separation to allow that pedestrian to pass through the doorway or fare gate 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. Exhibit 7-17 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 7-17 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Exhibit 7-17
Observed Average Doorway Headway and Capacity(R6)

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

Doorway Level of Service

The LOS criteria used for evaluating doorways are the same as those used for evaluating walkways (see Exhibit 7-3). The objective is to maintain a desirable average pedestrian flow rate (or walking speed) throughout the walkway system. 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.

Evaluation Procedures

Determining the Number of Doorways

Similar to the evaluation procedures for walkways, the procedure to determine the required number of doorways is based on maintaining a desirable pedestrian LOS. Consideration should be made of pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids. 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 7-3.
2. Estimate the peak 15-minute pedestrian demand.
3. Compute the design pedestrian flow (persons per minute) by dividing the 15-minute demand by 15.

4. Compute the required width of the doorway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
5. Compute the number of doorways required by dividing the required entrance width by the width of one doorway (always round up).
6. Determine whether the design pedestrian flow exceeds the entrance capacity by following the procedures below.

Determining Doorway 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 7-17 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 doorway capacity by 60.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity value for doors and gates should be used in place of the values presented above. In the 2000 edition, this value was a pedestrian flow rate of 2.27 p/in/min (27.2 p/ft/min, or 89.3 p/m/min), with a minimum door width of 36 in. (914.4 mm).(R11) The larger number of doorways resulting from the two calculations—design LOS or emergency evacuation—should be selected.

STAIRWAYS

Design Factors

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 7-18 shows typical treatments.

Exhibit 7-18
Stairway Examples

(a) Los Angeles (b) Portland, Oregon

The capacity of a stairway is largely affected by its width. The width of stairway affects the pedestrians' ability to pass slower-moving pedestrians and to choose a desirable speed. Unlike walkways, a minor pedestrian flow in the opposing direction on a stairway can cut capacity in half; therefore, stairway design should consider directionality of flow.

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. This is at least as important as ensuring that adequate space is provided at entry points.

Critical passenger flows on stairways occur in the ascending direction.

Evaluation Procedures

The LOS thresholds for stairways are based on average flow rate. Exhibit 7-7 summarizes the LOS criteria for stairways. The threshold between LOS "E" and "F" (17 pedestrians per foot of width per minute or 55.8 p/m/min) represents the maximum capacity of a stairway.

When designing stairways, the following factors should be taken into consideration:(R6)

- 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 reduce energy expenditure and to increase 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 are the steps necessary to calculate the width of stairway, stairway capacity, and queuing area required for a given peak pedestrian volume.

Stairway Width

The procedures to determine the required stairway width are 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 51.8 p/m/min) may be assumed. Consideration of pedestrian characteristics at a stair location should be incorporated into the analysis.

The following is a list of steps recommended for determining the required stairway width:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 7-7.
2. Estimate the directional peak 15-minute pedestrian demand for the stairway.
3. Compute the design pedestrian flow (persons/minute) by dividing the 15-minute demand by 15.
4. Compute the required width of stairway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.

5. 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.

Stairway Capacity

As discussed above, the capacity of a stairway is taken to be 17 p/ft/min (51.8 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 (ped/min) by multiplying the width of stairway by 17 p/ft/min (51.8 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.

Size of Stair Queuing Area

1. Compute the capacity of the stairway using the above procedures.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the stairway 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 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 2000 edition, these values were the following for the up direction: a pedestrian flow rate of 1.59 persons per inch per minute (19.1 p/ft/min or 62.6 p/m/min), and a vertical component of travel speed of 50 ft/min (15.24 m/min). In the down direction, the values were a pedestrian flow rate of 1.82 p/in/min (21.8 p/ft/min or 71.6 p/m/min) and a vertical component of travel speed of 60 ft/min (18.3 m/min).(R11) Exit stairs should be a minimum 44 in. (1.12 m) wide; 48 in. (1.22 m) wide if adjacent to an "area of rescue assistance" as defined by the ADA. The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

ESCALATORS

Design Factors

Escalators (Exhibit 7-19) 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 7-19
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%. An interesting finding is that the practice of walking on a moving escalator does not significantly increase escalator capacity. 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.

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 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.

Escalator Capacity

Escalator manufacturers rate the maximum theoretical capacity of their units based on 100% step utilization. Studies have shown, however, that 100% utilization is never obtained. Escalator steps not being utilized under a heavy demand may be due to any of the following factors:

- Intermittent pedestrian arrival process,
- Pedestrian inability to board quickly,
- Pedestrians carrying baggage or packages, and
- Pedestrians' desire for a more comfortable space.

Because 100% utilization is typically not attainable, nominal design capacity values have been developed (see Exhibit 7-20). These values represent a step utilization of 1 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. (1.1-m) wide escalator.

Exhibit 7-20
Nominal Escalator Capacity Values[R6]

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	4,080	68
			120	36.6	5,400	90

Evaluation Procedures

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 recommended for determining the required number of escalators:

1. Estimate the directional peak 15-minute pedestrian demand for the escalator.
2. Compute the design pedestrian flow (persons per minute) by dividing the 15-minute demand by 15.
3. Based on the width and speed of the escalator, choose the nominal capacity (pedestrians per minute) from Exhibit 7-20.
4. Compute the required number of escalators by dividing the design pedestrian flow by the nominal capacity of one escalator.

Size of 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 assumed to be 1 minute.) 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 7-20.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the escalator at one time. (Assume pedestrians having to wait more than 1 minute at the escalator will take the stairs, if available.)
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 2000 NFPA 130 values for stopped escalator capacity and pedestrian travel speed may be found in the preceding section on stairways. Escalators shall not account for more than one-half of the exit capacity, and one escalator shall be considered to be out of service.[R11]

MOVING WALKWAYS

Moving walkways (Exhibit 7-21) have been installed in a number of transit stations and terminals around the world and are very common in larger airports. 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). Individual moving walkways can be constructed in varying lengths, but 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.

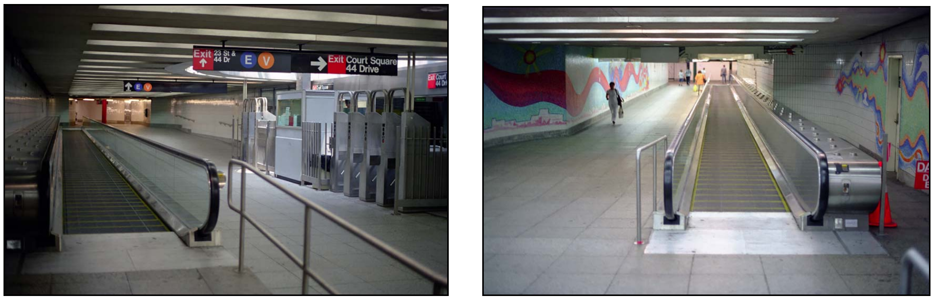


Exhibit 7-21
Moving Walkway Examples (New York)

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 are under development. Some designs use sequential rubber belts or metal rollers to accelerate pedestrians at the beginning of the moving walkways, then decelerate them at the end of the run. Other designs use metal pallets somewhat like those in escalators and achieve acceleration and deceleration by compressing overlapping pallets or by moving on a non-linear course.

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 (1) to carry those who cannot or do not wish to use the moving walkway and (2) to serve as an alternate route when a walkway is undergoing maintenance. Similar to escalators, it may not be possible to enter and walk on a moving walkway that is undergoing maintenance if the end plates have been removed.
- The ongoing cost of operating and maintaining the moving walkway.

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 the pedestrian's 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 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.

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 persons per minute or 5,400 persons per hour.

Evaluation Procedures

The procedures to determine the required number of moving walkways and the queuing areas at each end are similar to the procedure for escalators. If volumes in either direction are expected to approach or exceed the estimated capacity of 90 persons per minute for a double-width moving walkway, field studies at a moving walkway of comparable width and speed are recommended to confirm capacity.

Designing for Emergency Evacuation

The NFPA 130 standard(R11) does not address moving walkways. It is prudent to calculate emergency evacuation flow under the assumption that power is off.

ELEVATORS AND LIFTS

Design Factors

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

http://www.access-board.gov/adaag/html/adaag.htm

Elevators, lifts, or ramps 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. 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, Oregon (Washington Park), elevators are the sole means of passenger access to and from stations, not including emergency stairs. 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.

On-going elevator maintenance is important for keeping stations consistently ADA accessible.

Good, on-going 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 7-22 shows a typical elevator location 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, Oregon) (b) Station Circulation (Los Angeles)

Exhibit 7-22
Elevator Application Examples

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 seconds 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.

Evaluation Procedures

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 and baggage 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.

Designing for Emergency Evacuation

Elevators are not considered part of an evacuation route, and their capacity should not be included in evacuation design.

RAMPS

Design Factors

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 it 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.

Ramp Level of Service

LOS thresholds have not been established for ramps, but 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 NFPA 130 standard specifies ramp capacities and pedestrian travel speeds for use in emergency evacuation design. The 2000 NFPA 130 treats ramps with a grade of 4% or less the same as level walkways, while ramps with a grade over 4% are treated as stairways. The corresponding capacity and pedestrian travel speed values can be found in the previous sections on walkways and stairways.(R11)

FARE CONTROL BARRIERS, GATES, AND TURNSTILES

Design Factors

Different types of fare gates have different capacity characteristics.

Fare gates limit the capacity of a walkway by imposing restricted lateral spacing and by requiring pedestrians to perform an activity that consumes additional time. Because of these restrictions on capacity, fare gates will impact the overall capacity of a pedestrian walkway system within a transit terminal, and therefore will require additional design considerations. Fare gates or turnstiles are typically applied at heavy rail stations to control fare payment. They are applied to a lesser extent at commuter rail and light rail stations, due to the proof-of-payment system associated with most of these systems. Fare gates are required to comply with the ADA Accessibility Guidelines, although turnstiles and some types of gates are not considered part of an accessible route.

http://www.access-board.gov/adaag/html/adaag.htm

Exhibit 7-23 illustrates the placement and operation of fare gate configurations in a transit terminal. There are three different types of fare gates applied in stations:

1. Free admission (a barrier only),
2. Coin- or token-operated, and
3. Automatic ticket reader.

Coin-operated fare gates may have single or double slots to accept change. Automatic fare gates, using magnetic stripe farecards, have been used on newer heavy rail systems with distance-based fares, such as BART in the San Francisco Bay Area and Metro in Washington, DC, and are increasingly being used in other systems such as MTA-New York City Transit. Some agencies—particularly ferry systems—use staff to check and collect tickets before allowing passengers access to the waiting area or vessel. This form of gate 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 fare gates 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 7-23
Fare Gate Examples

(a) New York

(b) San Francisco

The effect of fare gates on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a fare gate, there must be sufficient time separation to allow that pedestrian to pass through the fare gate before the next pedestrian arrives. If the times between successive pedestrians are too close, a pedestrian queue will develop.

The capacity of a fare gate is therefore determined by the minimum time required by each pedestrian to pass through. Exhibit 7-24 summarizes observed average headways for different types of fare gates. Although it is recommended that headways be recorded at fare gates that are of a similar design and operation to those under investigation, the values in Exhibit 7-24 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Exhibit 7-24
Observed Average Fare Gate Headways and Capacities(R6)

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
Card reader (various types)	1.5-4.0	25-40
High entrance/exit turnstile	3.0	20
High exit turnstile	2.1	28
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

Fare Gate Capacity

Fare gates and turnstiles are evaluated based on a design volume-to-capacity (*v/c*) ratio, rather than a design LOS. The selected *v/c* ratio should allow some room for growth in passenger flow.

Evaluation Procedures

Determining the Required Number of Fare Gates

The procedure to determine the required number of fare gates is based on determining the capacity of individual fare gates 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 is a list of steps recommended for determining the required number of fare gates:

1. Estimate the peak 5- to 15-minute passenger demand.
2. Compute the design pedestrian flow (passengers per minute) by dividing the demand by the number of minutes.
3. 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.

Determining Fare Gate Capacity

When possible, the capacity of a specific fare gate type should be determined through field observations of an identical or similar gate in the same system or a system with a similar fare structure and fare medium. Observations should be made when a fare gate is operating at maximum capacity, as evidenced by a queue at the entry to the gate. As an alternative, an estimated capacity from Exhibit 7-24 can be used. Compute the total capacity of a fare control array by summing the capacity of all the gates in the array. Adjustments should be made as appropriate to reflect special pedestrian characteristics.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 divides fare gates into two categories: (1) fare collection gates that provide barrier-free egress in emergency mode and (2) turnstiles that free wheel in the exit direction in emergency mode. The 2000 NFPA 130 capacity values are 50 persons per minute for the former and 25 persons per minute for the latter.(R11)

TICKET MACHINES

Design Factors

At a transit station, passengers pay their fares at ticket machines or pay booths before they enter the platform area. Exhibit 7-25 illustrates different ticket machine/booth configurations at transit stations. At larger heavy rail stations, several ticket machines are typically provided to handle peak passenger demand for tickets. At light rail stations, at least one ticket machine is provided on each platform, but some redundancy is desirable in case one machine is out of service. Conversely, a ticket machine may not be provided on a light rail or bus rapid transit platform that is used primarily for alighting, especially if ticket machines elsewhere are readily accessible. Staffed ticket booths are used at older heavy rail stations and at many commuter rail stations.

Transit systems are increasingly using either electronic fare media or proof-of-payment systems. Electronic media increase the importance and the complexity of ticket vending machines, with varying effects on the fare control systems.

Ticket Machine Level of Service

Passenger processing times at ticket vending machines vary widely depending on the particular characteristics of the ticket vending machine and the fare structure of the transit system. Passenger processing time at ticket machines increases with complex zone fare systems, which require some deciphering by the passenger at the machine prior to paying the correct fare. Infrequent passengers require more time to purchase fares than regular commuters who have had practice using the machines. Ticket vending machines must be made accessible for persons with disabilities, including Braille writing and other design features.

Exhibit 7-25
Ticket Machine Examples

(a) San Francisco

(b) New Jersey

Evaluation Procedures

To identify the required number of ticket machines at a station, pre-testing of the particular machine to be purchased could prove beneficial to approximate an average passenger processing time. In many cases, the number of machines or booths will be restricted by space, personnel, or cost constraints.

SIGNAGE AND PASSENGER COMMUNICATION SYSTEMS

Signage and Information Displays

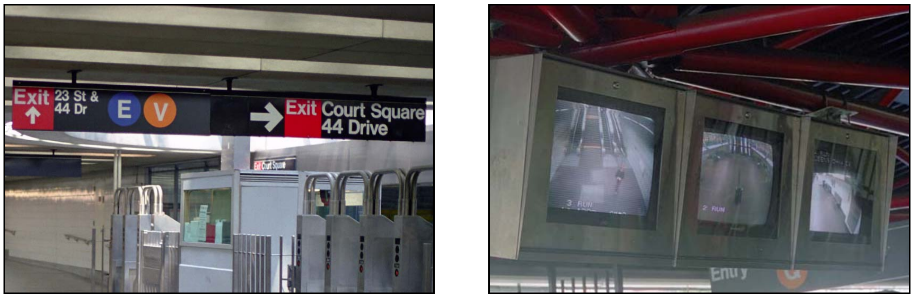
Station signage, illustrated in Exhibit 7-26, provides information to passengers both in the station and on transit vehicles. Signs can direct passengers to loading areas or platforms for various transit services, nearby destinations, and emergency evacuation routes. System maps, schedules, fare information, 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 should be accessible to persons with disabilities, including Braille signage, and should be placed so that they are accessible to wheelchair users.

Exhibit 7-26
Signage and Communication System Examples

(a) Posted System Information

(b) Real-Time Schedule Information



(c) Wayfinding Information

(d) Video Security Monitors

(e) Emergency Call Box

(f) Elevator Availability Information

Photo locations:
(a) San Diego
(b) Denver
(c) New York
(d) New York
(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 may 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.

Real-Time Passenger Information Systems

In recent years, new electronic technology has been developed to provide improved traveler information systems. For transit stations, "real-time" passenger communications can assist in managing passenger flows and queues. This can include providing information on bus and train departure times, bus and train berth locations, and out-of-service elevators and other facilities.

PASSENGER AMENITIES

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

Passenger amenities are those elements provided at a bus stop or transit station to enhance comfort, convenience, and security for the transit patron. Amenities include such items as shelters, benches, vending machines, trash receptacles, lighting, phone booths, art, and landscaping. The effects that particular amenities have on transit ridership is not well known. 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 7-27. Examples of passenger amenities at transit stops and stations are illustrated in Exhibit 7-28.

Exhibit 7-27
Types of Passenger Amenities at Bus Stops(R15)

Amenity	Advantages	Disadvantages
Shelters	• Provides comfort for waiting passengers • Provides protection from climate (sun, glare, wind, rain, snow) • Help identify the stop/station	• Requires maintenance, trash collection • May be used by graffiti artists
Benches	• Provides comfort for waiting passengers • Help identify the stop/station • Low-cost when compared with installing a shelter	• Requires maintenance • May be used by graffiti artists
Vending Machines	• Provides reading material for waiting passengers	• Increases trash accumulation • May have poor visual appearance • Reduces circulation space • Can be vandalized
Lighting	• Increases visibility • Increases perceptions of comfort and security • Discourages "after hours" use of bus stop facilities by indigents	• Requires maintenance • Can be costly
Trash Receptacles	• Provides place to discard trash • Keeps bus stop and surroundings clean	• May be costly to maintain • May be used by customers of nearby land uses • May have a bad odor • May be removed for security reasons
Telephones	• Convenient for transit patrons • Provides access to transit information and emergency services	• May encourage loitering at bus stop • May encourage illegal activities at bus stop

Exhibit 7-28
Passenger Amenity Examples

(a) Shelter & Bench (Denver)

(b) Telephones (Denver)

(c) Vending Machines (Brisbane, Australia)

(d) Lighting (Cleveland)

(e) Trash Receptacle (Albuquerque)

(f) Art (Los Angeles)

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.

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.

BICYCLE STORAGE

Bicycle storage may be provided at transit stations where demand exists and space allows. Bike 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 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.

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. 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. Parking structures are used where land is at a premium and where a substantial number of parking spaces are required.

Exhibit 7-29
Park-and-Ride Lot Examples


(a) Cleveland
(b) Houston

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 (35 to 100 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 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.

KISS-AND-RIDE FACILITIES

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

Kiss-and-rides are dedicated auto loading areas at stations, where transit patrons can be dropped off and picked up by another person in a vehicle. 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 (though curb space is needed to handle the drop-off). As with park-and-ride facilities, the sizing of kiss-and-ride facilities is reflective of the demand and physical constraints of the site. Several rail stations in Toronto use a "carousel" design incorporating an enclosed waiting area.

Exhibit 7-30
Kiss-and-Ride Examples

(a) Denver (b) Boston

(c) Toronto

CHAPTER 5. REFERENCES

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CHAPTER 6. EXAMPLE PROBLEMS

Example Problem 1

Derived from a problem in the 1985 HCM.(R10,R14)

The Situation

A transit agency plans to construct a suburban transit center.

The Question

What are the "base year" 2000 and "design year" 2015 berth requirements?

The Facts

- The bus lines serving the proposed transit center are identified below. Year 2000 data are based on actual schedules, while year 2015 data are based on a growth forecast of 60% for local bus service and 100% for freeway bus service.
- Bus berths will be assigned according to principal geographical destinations.
- Bus dwell times will be approximately 5 minutes per bus passing through the center and 8 minutes for buses that begin and end trips there.

		Peak Direction Buses		Off-Peak Dir. Buses		Service Type
Rte. #	**Route Name**	**2000**	**2015**	**2000**	**2015**	
	LOCAL SERVICE					
42	Holman Crosstown	8	13	0	0	Terminating
68	Brays Bayou Crosstown	4	6	0	0	Terminating
76	Lockwood Crosstown	4	6	4	6	Through
77	MLK Limited	6	10	6	10	Through
	Subtotal Local	*22*	*35*	*10*	*16*	
	EXPRESSWAY SERVICE					
242	Clear Lake Park-and-Ride	3	6	1	2	Through
245	Edgewood Park-and-Ride	3	6	1	2	Through
250	Hobby Park-and-Ride	2	4	1	2	Through
255	Fuqua Park-and-Ride	4	8	1	2	Through
41	Garden Villas Limited	2	4	1	2	Through
147	Sagemont Express	2	4	1	2	Through
	Subtotal Express	*16*	*32*	*6*	*12*	
	TOTAL	**38**	**67**	**16**	**28**	

Comments

- In 2000, 22 local buses and 16 express buses use the transit center in the peak direction, while 10 local buses and 6 express buses will use it in the off-peak direction.
- Bus dwell times are longer than the 3-minute passenger service time needed to fill an empty bus to seated capacity, assuming that exact fares are paid on the bus, to allow for schedule irregularities and (for the terminating routes) driver layover time.

Steps

The table on the next page provides estimated berth requirements for 2000 and 2015. The berths were estimated as follows:

1. The bus routes were grouped by geographic destination in 3 categories.
2. The "capacity" of each type of service was obtained by the equation $c = 60 / t_d$, where t_d was the specified dwell time (clearance time was neglected, as it is short in comparison with the dwell times at the transit center). Thus a 5-minute dwell time could accommodate 12 buses/berth/hour; an 8-minute dwell time, 7.5 buses/berth/hour.

3. The number of inbound berths for the a.m. peak hour was computed by dividing the number of buses by the berth capacity. Thus, for lines 42 and 68, in 2000, 12 buses need 12 / 7.5 or 1.6 berths, rounded up to 2 berths.
4. The bus routes that start at the center need only inbound berths. The other bus routes need an equal number of outbound berths to accommodate p.m. peak hour bus flows and to ensure that each major geographic destination would have its own specified area.

The Results

For the year 2000, the following calculations result:

Route	Service Type	Dwell Time/Bus (min)	Buses/ Berth/ Hour	A.M. Inbound Buses	Inbound Berths	Max. Outbound Berths for P.M.	Total Berths
			LOCAL SERVICE				
42-68	Start	8	7.5	12	2	0	2
76	Through	5	12	4	1	1	2
77	Through	5	12	6	1	1	2
			Subtotal	*22*	*4*	*2*	*6*
			EXPRESSWAY SERVICE				
All	Through	5	12	16	2	2	4
			TOTAL	**38**	**6**	**4**	**10**

For the year 2015, the following calculations result:

Route	Service Type	Dwell Time/Bus (min)	Buses/ Berth/ Hour	A.M. Inbound Buses	Inbound Berths	Max. Outbound Berths for P.M.	Total Berths
			LOCAL SERVICE				
42-68	Start	8	7.5	19	3	0	3
76	Through	5	12	6	1	1	2
77	Through	5	12	10	1	1	2
			Subtotal	*35*	*5*	*2*	*7*
			EXPRESSWAY SERVICE				
All	Through	5	12	32	3	3	6
			TOTAL	**67**	**8**	**5**	**13**

The total berth requirements represent the sum of the inbound and outbound berths. As a result, 10 loading positions are needed for year 2000 conditions, and 13 loading positions are needed for year 2015 conditions. Ideally, 15 loading positions should be provided to account for growth and traffic fluctuations within the peak hour.

Note that 38 inbound buses with a berth capacity of 10 buses/berth/hour would require only 4 inbound loading positions in 2000 if routes were not separated geographically. However, this is *not* advisable when one considers clarity to the riding public, so 6 berths are anticipated based on the grouping shown above.

Example Problem 2

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-minute 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 minute headways (i.e., 8 trains/hour/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 minutes 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 minutes 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.

Comments

LOS "C" is a reasonable design level for a station under typical daily conditions. The NFPA 130 evacuation standard(R11) 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 minutes, 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 minutes, assuming their trains are running one headway late.

Outline of Solution

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 minutes. The resulting width will then be compared with the width required to evacuate the platform within 4 minutes. The larger width will control design.

Steps

Design Periods

Peak-hour volumes should be converted to peak 15-minute volumes by multiplying by the peak hour factor:

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

For example, the peak-15-minute 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-minute entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak-15-minute 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 minutes. 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 minutes. 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 minutes between trains in a given direction, up to half of the entering volume during the peak 15 minutes 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.

Stairway Width

Exhibit 7-7 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:

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

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 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:

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

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 minutes. One of the four escalators should be assumed to be out of service. A stopped escalator can serve 1.59 p/in/min in the up direction, according to the NFPA 130 standard;[(R11)] thus a 40-in. escalator can serve (40 in.)(1.59 p/in./min), or 63 p/min. In 4 minutes, three escalators could serve (4 min)(3 escalators)(63 p/min/escalator), or 756 people, leaving 1,459 people to be served by stairs. The total stairway width required to serve these people in 4 minutes is:

$$\text{Stairway width} = \frac{1{,}459\text{ p}}{4\text{ min} \times 1.59\text{ ped/in./m}} = 229\text{ in. (19.1 ft)}$$

The Results

Two 10-foot stairways would be required. Evacuation needs, in this case, control the stairway size.

Although not addressed in this example problem, 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.

Example Problem 3

The Situation

A new rail station will be constructed below grade with a mezzanine and a single center platform. The initial concept for the platform level is to connect it 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. Each stair will be 10 feet wide.

The Questions

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

The Facts

- For the design year, four-car trains are expected to run at 7 to 8 minute headways (i.e., 8 trains/hour/direction). Each car will be 75 feet long and will have a maximum schedule load of 200 persons.
- The a.m. peak hour exiting and entering demands are 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 minutes 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 minutes 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 average peak hour factor currently observed on the system is 0.714.

Comments

LOS "C" is a reasonable design level for a station under typical daily conditions. The NFPA 130 standard(R11) 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 minutes, 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 minutes, assuming their trains are running one headway late.

Steps

Design Periods

Peak-hour volumes should be converted to peak 15-minute volumes by multiplying by the peak hour factor:

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

For example, the peak-15-minute 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-minute entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak-15-minute 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 minutes. 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 have been able to board the train.
- *Outbound train*: an average train carries 300 people during the peak 15 minutes. 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 minutes between trains in a given direction, up to half of the entering volume during the peak 15 minutes 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.

Platform Size

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 section 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 7-8) and at least 15 ft^2/p is required for walking space (from Exhibit 7-3).
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 minutes, two trains arrive in each direction during the 15 minutes, and thus one-half of 1,015 people could be present.)
4. *Calculate the required waiting space.* Multiplying 507 passengers by 7 ft^2/p results in a required area of 3,549 ft^2 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 minutes, 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 7-20, 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 Problem 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.
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 31 feet wide to accommodate the central stairs (10 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 9,300 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 (9,300 – 900 – 550 – 686), or 7,164 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, 1,432 people could be accommodated on the platform. This is about 40% higher than the peak 15-minute entering demand. At a minimally tolerable crowding level of 3 ft²/p, about 2,388 people could be accommodated, representing about 80% of the p.m. peak hour entering demand. However, most passengers would find this amount of crowding to be uncomfortable, and it is greater than 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.

Example Problem 4

Derived from a problem in Fruin.(R6)

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 minutes of each other, carrying 225 and 275 passengers, respectively.
- The remaining trains in the peak period are on 4-minute headways.
- The platform is 275 meters long, and 4.6 meters 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 36.6 m/min, 1-meter-wide escalators in this example), as opposed to the nominal capacity of 90 p/min/minute given in Exhibit 7-20.

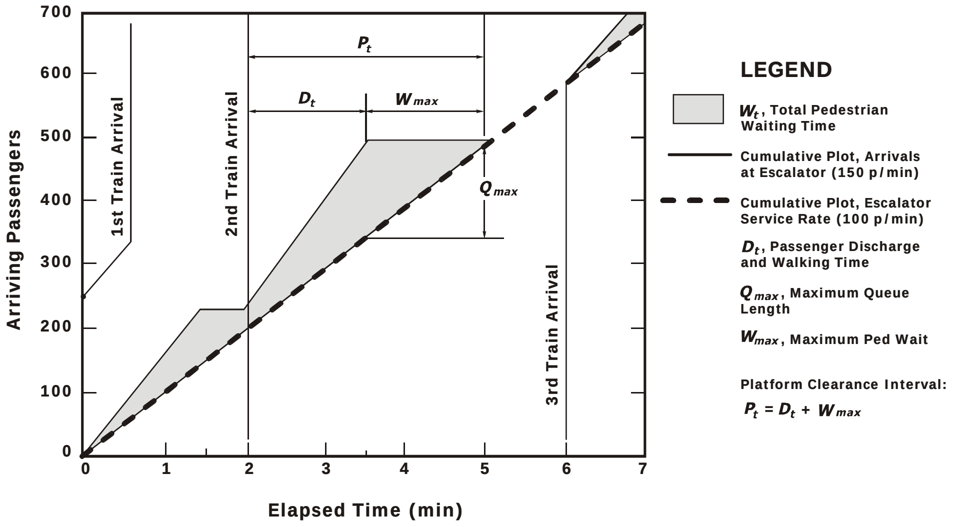
Steps

Construction of the Time Clearance Diagram

1. A graph is constructed (see the figure on the next page), with time, in minutes, as the horizontal axis, and pedestrians as the vertical axis.
2. The escalator capacity of 100 p/min is then drawn (dashed sloped line).
3. 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.

$$\text{Total arrival time} = \frac{\text{1/2 platform length}}{\text{average walking speed}} = \frac{137.5\text{ m}}{91.4\text{ m/min}} = 1.5\text{ min}$$

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



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.

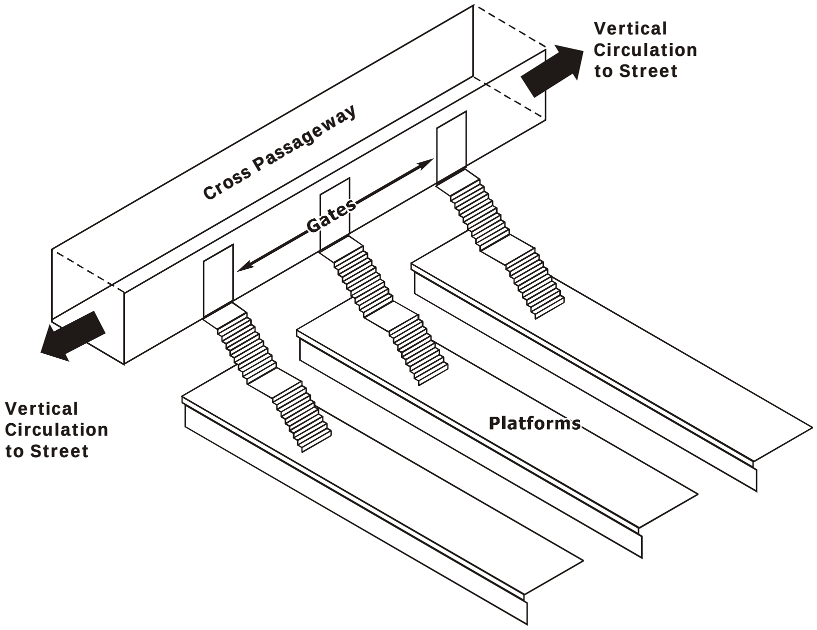
The maximum waiting time for escalator service after the first train arrival is 1 minute. The average passenger waiting time is 15 seconds. After the second train arrival, the maximum waiting and maximum queue size builds up to 1.5 minutes and 150 passengers, respectively. If it is assumed that passengers will divert to the stairs if the maximum escalator wait exceeds 1 minute, a 1-minute-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.

Example Problem 5

Derived from a problem in Benz.(R2)

The Situation

A new cross passageway (depicted below) 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.



The Question

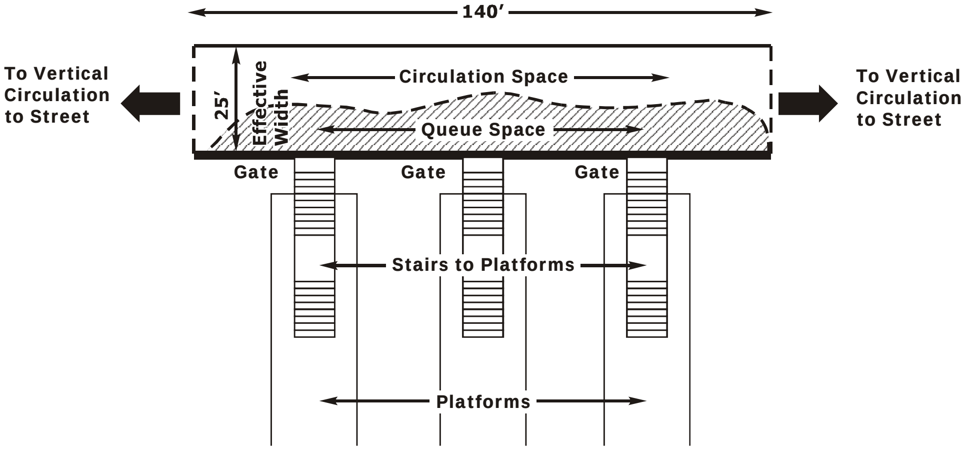
Can the corridor meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate?

The Facts

- Surveys at the station show that passengers departing on trains typically start to gather in front of a gate about 23 minutes 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 minutes 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 the figure on the next page, 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 minute 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.



Comments

- 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 minute before the opening of the gate when the maximum accumulation of waiting passengers will occur.

Steps

With a design criterion of LOS "B," the average pedestrian queuing area is 10 ft²/ped (see Exhibit 7-8). This classification 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. 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 ft² are assumed to be evenly distributed along the 140-foot linear dimension of the space. Therefore, the queue is expected to require the following width at the widest point:

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

This leaves 11.1 feet available for the flow of the 167 circulating passengers who would walk through the cross passageway during the 1-minute 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 7-3, this identified pedestrian flow rate equates to LOS "C" to "D." In this level of service 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.

Example Problem 6

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

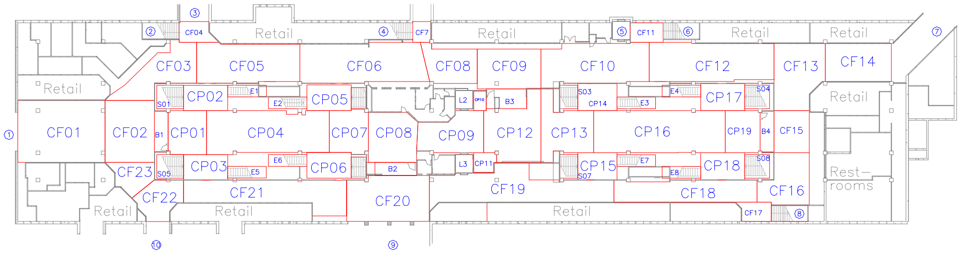
The Question

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.

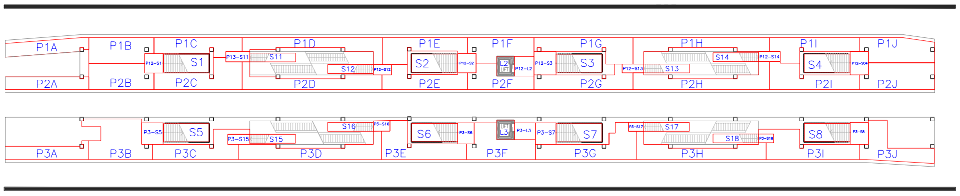
The Facts

- The station has three levels underground: a concourse level and two platform levels that each have two platforms and three tracks. As shown in the following figure, the concourse level includes a paid area surrounded by a free area lined with narrow retail establishments. The second figure 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.

Station Concourse



Upper Platform Level



Approach

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 on the previous page. 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 formulas, which, due to extensive cross-referencing of tables, are only meaningful in the spreadsheet environment.

Steps

Analysis is conducted on a series of custom spreadsheets as follows:

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 and any other, 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 is input into the model in the form of a.m. and p.m. peak 5-minute origin-destination matrices.

Routing Assignment

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.

Walk Volumes

This worksheet calculates the pedestrian volumes passing through each zone by multiplying the origin and destination volumes with the percentage assignment for each zone.

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 (1) the full length of the zone, (2) half the length, either as an average for people who end their walk in the zone or cut through it diagonally, or (3) 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).

Dwell Percent

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.

Dwell Time

This worksheet includes an average time in seconds that pedestrians who dwell in a zone spend there. On platforms it 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 where 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 (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 tends toward capacity, the dwell times in the prior zones are increased by the formula.

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.

Level of Service

The operating condition of each zone is assessed by levels of service. Design capacity for all elements is considered to be the break point 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.

	Volume-to-Design Capacity Ratios	
Level of Service	**for Walk/Standing Zones**	**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.

APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 7-1m
Pedestrian Speed on Walkways(R6)

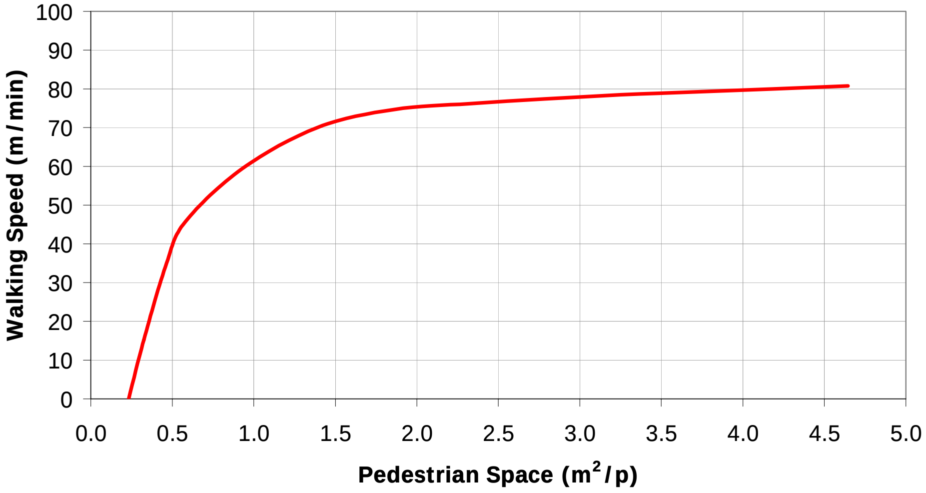


Exhibit 7-2m
Pedestrian Flow on Walkways by Unit Width and Space(R6)

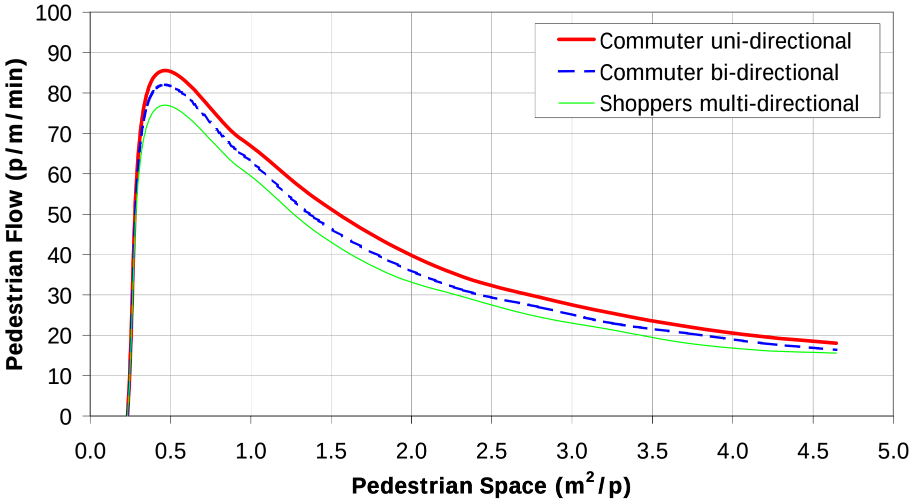


Exhibit 7-5m
Pedestrian Ascent Speed on Stairs(R6)

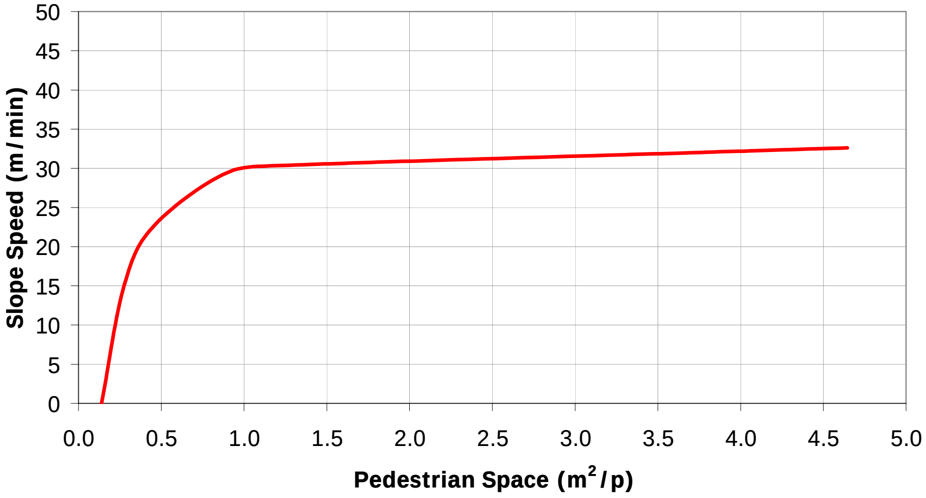


Exhibit 7-6m
Pedestrian Flow Volumes on Stairs(R6)