CHAPTER 14
Parking and Terminals

Willard A. Alroth
Vice President
Paul C. Box and Associates, Inc.

Introduction
Parking facilities are terminals used for temporary vehicle storage and are an integral part of the overall transportation system. The total valuation of parking facilities in the United States has been estimated at $48 billion.\(^1\) Traffic engineers need to understand the function of these facilities and how to plan, design, and operate them.

This chapter deals with functional design and operation of parking lots and garages. The user must be given primary consideration in the design and operation of parking facilities. These include elements of access, traffic circulation, dimensions, fee collection, lighting, traffic control devices, security issues, drainage, and maintenance. Design aspects of large parking generators as well as a review of curb parking practices are discussed. Design of parking for trucks and other special purpose vehicles is also covered.

The planning elements of location, needs, zoning, programs, administration, and financing of parking facilities are separately covered in Chapter 14 of the Institute of Transportation Engineers (ITE) Transportation Planning Handbook. The reader is encouraged to refer to both the Traffic Engineering Handbook and the Transportation Planning Handbook for a more thorough discussion of parking planning, design, and operational elements.

Definitions
Some terms related to the parking field are closely related to parking design. These are presented to aid the reader.

- Cross Aisles — breaks in long parking rows to allow internal circulation.
- Free-Standing Garage — a structure for parking vehicles with little or no area devoted to other uses.
- Module — one access aisle servicing a row of parking stalls on one or both sides of the aisle.
- Multi-use Structure — a structure that contains uses other than parking, such as retail at sidewalk level and offices or residential above parking levels.
- Parking Generator — a single development or activity center that attracts persons driving vehicles.
- Parking Lot — a single surface facility without any structural cover.
- Parking Stall — an area large enough to accommodate one vehicle, including space for door opening, with unrestricted access to an aisle (no blockage by another parked vehicle), excluding maneuver space.

• Turnover—the number of different vehicles parked at a specific parking stall or facility during a specific period of time; a measure of stall use.

• Walking Distance—the actual distance traveled by foot from the parking facility to the trip destination.

Parking Operations Related to Facility Type

There are two general types of facilities for parking: at the curb or in off-street lots or structures. The total number of motor vehicles in most cities could not possibly be parked at the curb. Even if such space were available, the cost of congestion and accidents would be unacceptable. Off-street facilities range in size from the few stalls typically needed for a single-family dwelling unit to parking garages that can hold thousands of vehicles, often found at large generators such as airports. Apartment buildings usually provide a common parking facility to serve visitors as well as residents. Commercial or industrial developments generally have self-contained parking to serve shoppers, employees, and visitors. In all of these general cases, the parking is owner-supplied, usually free, and unavailable to the general public. Parking is typically by the vehicle driver (self park), admittance is normally free-flowing, and there is no need to attract parkers, collect fees, or control revenue.

So-called public parking facilities represent a centralized, more general-purpose use. Parkers usually have a choice of several destinations and often alternate places to park. Such a facility open to the general public usually needs to justify the investment in its construction. Sometimes parking is free (in a structure, for example), with the cost paid by assessment of some type such as a benefit district, or revenue from parking meters. More often, a parking fee is charged.

The design of a general-purpose parking facility must consider the type of operation, such as attendant parking, self parking, or by a combination. The most economical operation occurs where drivers park their own vehicles. It is sometimes feasible to use attendants to park vehicles in highly congested areas, or facilities may operate on both systems with certain areas reserved for self parking and others served by attendants.

Advantages of self parking over attendant parking include the following:

• single rows and clear aisles permit faster vehicle movement;

• owners take better care of their cars than the average attendant;

• insurance costs are usually lower;

• drivers prefer to self park because they may lock their vehicle and know it will not be handled by anyone else; and

• self parkers avoid the long delay often associated with attendant retrieval of cars.

Disadvantages of self parking include requirements for a larger stall and wider access aisle. Double parking in aisles cannot be used, which reduces total capacity and possible revenue. This applies, however, only when the facility is used to near capacity. Often the very substantial saving in labor cost by use of self parking more than offsets the difference.

An operational factor in design is the expected use by type of parker or generator served. Parking duration can be short term, long term, or a combination. Dimensions are often larger for short-term parkers because of the higher turnover and the need to provide easy access and circulation. A facility may serve many types of parking generators, particularly in a downtown area. However, those that serve special events such as stadiums or auditoriums require special considerations. Persons attending these generators typically arrive in a short time period and will all leave at the conclusion of the event. This requires greater capacity for the entrances, exits, and internal circulation system than needed for ordinary parking facilities.
If a fee is charged, several collection systems exist. These vary from pre-paying, such as self-deposit coin slots, to monthly stickers, parking meters and entry-ticket/cashier collection-on-exit systems.

Design Elements Related to Operations

The design of a parking facility is strongly influenced by its intended operation. Design elements and their operational features follow in successive steps:

1. vehicular access from the street system (an entry driveway).
2. search for a parking stall (circulation and/or access aisles).
3. maneuver space to enter the stall (access aisles).
4. sufficient stall size to accommodate the vehicle’s length and width plus space to open car doors wide enough to enter and leave the vehicle (stall dimensions).
5. pedestrian access to and from the facility boundary (usually via the aisles) and vertically by stairs, escalators, or elevators in multi-level facilities.
6. maneuver space to exit from the parking stall (access aisles).
7. routing to leave the facility (access and circulation aisles).
8. vehicular egress to the street system (exit driveway).
9. any revenue control system (may involve elements of entry, exit, or both).

The simplest form of off-street parking is a single stall at a home. Assuming a straight driveway, Steps 1 and 8 use the same lane and curb cut, and Step 9 does not apply. Steps 2 and 7 are rudimentary. Thus, a driveway serving a one-car parking stall or single-car garage cannot be considered to represent a second parking stall if it would block continuous access to the basic stall (however, most residential driveway and garage layouts violate this concept). Step 6 usually involves backing out into the public street or alley, as part of Steps 7 and 8. Herein lies the essential difference between low-volume parking and what generally should be practiced in facilities designed to handle more than a few cars. Except along alleys, larger lots should have all parking and unparking maneuvers contained off-street. Backing of large numbers of cars across sidewalks and into public streets increases congestion and creates hazards.

For the larger facilities, and particularly garages, the operational concept necessarily precedes structural, architectural, and other design elements. The concept begins with the question “who do we plan to serve?” From the answers, design features emerge such as user ease of access, security, vehicle-circulation and walk patterns, signing, lighting, and equipment needs.

Elements of Good Design

In designing facilities for more than a few stalls, high priority must be given to customer service, convenience, and safety with minimum interference to street traffic flow. Drivers wish to park their vehicles as close to their destination as possible. The accessibility, ease of entering, circulating, parking, unparking, and exiting are important factors. Adequate parking dimensions and good internal circulation are more important than a few additional stalls. Necessary elements include appropriate sight distances at ends of parking rows, on ramps, and at driveways, as well as provisions for pedestrian circulation. Signing, lighting, drainage, landscaping, and aesthetic compatibility with the surrounding area also warrant attention.
Basic Design Principles

Site Characteristics

Site dimensions, topography, and adjacent street profiles affect the design of parking facilities. The relation of the site to the surrounding street system will affect the location of entry and exit points and the internal circulation pattern.

Access Location and Design

Traffic volumes and intersection traffic controls on adjacent streets must be considered—particularly in the location of driveways or garage ramps. It is desirable to avoid locating access or egress points where vehicles entering or leaving the site would conflict with large numbers of pedestrians. Turning restrictions and one-way streets may limit points at which entrances and exits can logically be placed.

Driveways should be located to provide appropriate entrance and exit storage (reservoir) space, and should be an adequate distance from controlled intersections. Combined entry/exit points should preferably be located mid-block. At pay facilities, it is desirable to locate entry and exit points together so that attendants can monitor both in and out traffic from the same point. However, along one-way streets, the inward movement generally should not overlap the exit flow. Where entrances and exits are separated, placing the exit in the downstream portion of the block is preferable, while the entrance should be placed as far upstream in the block face as practical.

The basic or nominal design width for a two-way driveway serving a commercial land use is 9.1 m (30 ft) with 4.6 m (15 ft) radii. With greater volumes (such as for a community shopping center), an 11 m (36 ft) driveway may be appropriate, marked with two exit lanes that are each 3.0 or 3.3 m (10 or 11 ft) wide and a single entry lane 4.3 to 4.6 m (14 to 16 ft) wide to accommodate the off-tracking path of an entering vehicle. Very high-volume facilities, such as a regional shopping center or large office complex, may need twin entry and exit lanes, separated by a median 1.2 to 3.6 m (4 to 12 ft) wide, with 6.1 to 9.1 m (20 to 30 ft) radii. One-way driveways may be narrower, perhaps 4.6 m (15 ft). Furthermore, the full-size radius is needed only on the side exposed to right-turn entry or exit. Except in downtown areas, or other locations subject to high pedestrian conflict, the driveway design should expedite a rapid entry or exit flow to reduce the conflict caused by speed differential with street traffic.

Left-turn access from two-way streets has been found to represent the greatest accident potential at commercial driveways along major streets. Left-turn movements also create the most congestion. Depending on the volume of turns into the driveway, and the volume of opposing flow, it is usually desirable to provide left-turn lanes (exclusive or as part of a continuous two-way left-turn lane), for service to moderate- and high-volume parking facilities. Sometimes right-turn lanes are also used, but these have far less value in terms of safety and reduction of congestion than is the case for left-turn lanes. The primary application of right-turn or deceleration lanes is added capacity at signalized access points, or to reduce the speed differential effect where a high-volume driveway connects to a high-speed route. Normally, street access to a parking facility is unrestricted. Where left-turn entry is to be prohibited, a barrier median is preferred. Without a barrier, NO LEFT TURN signs are an alternative. Left-turn exit is generally controlled by a channelizing island, plus NO LEFT TURN or RIGHT TURN ONLY signs.

All exit movements must be controlled so as to assign right-of-way to street traffic. The basic traffic ordinance requiring drivers to stop before crossing a sidewalk or entering the street is often adequate. At higher volume levels, STOP signs are sometimes used. At very high volumes, traffic signals may be appropriate.²

The access/egress capacity needed for a facility relates to the expected rates of arrival or departure. The expected peak 15-min flow rate is converted to an hourly rate and is known as either a service rate or acceptance rate. The volume depends

---


on the type of generator served, user characteristics (employee, shopper, etc.), and parking capacity. Volumes are typically expressed as a ratio of the number of vehicles to the number of parking stalls in the facility. Table 14–1 gives peak-hour ratios for a number of activities.

The number of vehicles that can enter (acceptance rate) or leave a parking facility, per lane, is related to the angle of approach (sharp turns have less capacity than straight-in runs), whether any control is used, the familiarity of the driver with the facility, the freedom of internal circulation (for entry), the amount of vehicular traffic on the streets (for exit) and the degree of conflict with pedestrians crossing the driveway. In general, for a self-parking facility with no control, the capacity per lane ranges up to 800 vph. One engineer has recommended a design value of 400 vph.5 Guidelines have been developed for considering capacities related to control methods, and also to street traffic (but not pedestrian sidewalk conflicts).6

---

### Table 14–1  Typical Peak-Hour Volumes as a Percentage of the Total Parking Stalls

<table>
<thead>
<tr>
<th>Type of Activity</th>
<th>A.M. Peak Hour</th>
<th>P.M. Peak Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>Hotel-motel</td>
<td>30–50</td>
<td>30–50</td>
</tr>
<tr>
<td>Residential</td>
<td>5–10</td>
<td>30–50</td>
</tr>
<tr>
<td>Office</td>
<td>40–70</td>
<td>5–15</td>
</tr>
<tr>
<td>Medical Office</td>
<td>40–60</td>
<td>10–20</td>
</tr>
<tr>
<td>Hospital</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visitor</td>
<td>30–40</td>
<td>40–50</td>
</tr>
<tr>
<td>Employee</td>
<td>60–75</td>
<td>5–10</td>
</tr>
<tr>
<td>Retail—commercial</td>
<td>10–30</td>
<td>10–20</td>
</tr>
<tr>
<td>Central business district</td>
<td>40–60</td>
<td>10–20</td>
</tr>
<tr>
<td>Airport — All</td>
<td>40–65</td>
<td>30–50</td>
</tr>
<tr>
<td>Short-term (0–3 hr)</td>
<td>50–75</td>
<td>80–100</td>
</tr>
<tr>
<td>Mid-term (4–24 hr)</td>
<td>10–30</td>
<td>5–10</td>
</tr>
<tr>
<td>Long-term (more than 24 hr)</td>
<td>5–10</td>
<td>5–10</td>
</tr>
<tr>
<td>Special events</td>
<td>Before event—(In)</td>
<td>After event—(Out)</td>
</tr>
<tr>
<td></td>
<td>80–100</td>
<td></td>
</tr>
</tbody>
</table>

*Maximum assumes a 30-min departure.


---

### Table 14–2  Vehicle Acceptance Rates of Large Parking Areas

<table>
<thead>
<tr>
<th>Approach to Entrance</th>
<th>Number of Studies</th>
<th>Unfamiliar Entrance1</th>
<th>Familiar Entrance2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight approach</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(no turn movement)</td>
<td>20</td>
<td>850</td>
<td>1,100</td>
</tr>
<tr>
<td>90° right turn</td>
<td>15</td>
<td>750</td>
<td>1,000</td>
</tr>
<tr>
<td>90° left turn</td>
<td>24</td>
<td>830</td>
<td>900</td>
</tr>
<tr>
<td>Oblique angle, right</td>
<td>8</td>
<td>650</td>
<td>1,000</td>
</tr>
<tr>
<td>Oblique angle, left</td>
<td>4</td>
<td>720</td>
<td>3</td>
</tr>
</tbody>
</table>

1 Includes racetracks, stadiums, and other facilities not frequently visited by the same individuals.

2 Includes industrial plants, military bases, and other facilities where the same drivers enter daily.

3 No data available.


---


Considering only the factors of approach angle and driver familiarity, the findings from 71 studies in 24 states are given in Table 14-2. For most parking facilities, lower rates of flow are to be expected—especially when sharp turns from the adjacent street and sidewalk conflicts are a factor. Looking solely at control methods and approach angle, a study in England found rates ranging from 180 to 970 vph as shown in Table 14-3. More detailed capacity data related to type of control are summarized from several studies in Table 14-4.

In summary, it can be seen that no single, all-encompassing value can be used to determine the lane capacity for access to or egress from a parking facility. This suggests a flexibility of design. When a two-way (entrance plus exit) driveway is used, the possibility of a three-lane design with reversible center lane should be considered.

Traffic Circulation

The ideal movement into a parking facility is a left-hand turn from a one-way street. This places the driver position on the inside of the turn, which allows better visibility and more accurate judgment of the vehicle placement, relative to curbs or other obstructions within the site.

### Table 14-3 Parking Gate Capacities

<table>
<thead>
<tr>
<th>Type of Control</th>
<th>EA*</th>
<th>STU(^b)</th>
<th>EA*</th>
<th>STU(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticket dispenser – automatic</td>
<td>525</td>
<td>300</td>
<td>650</td>
<td>400(^*)</td>
</tr>
<tr>
<td>Ticket dispenser – push button</td>
<td>450</td>
<td>250</td>
<td>525</td>
<td>300</td>
</tr>
<tr>
<td>Ticket dispenser – machine read</td>
<td>375</td>
<td>200</td>
<td>450</td>
<td>250</td>
</tr>
<tr>
<td>Coded-card reader</td>
<td>350</td>
<td>225</td>
<td>400</td>
<td>275</td>
</tr>
<tr>
<td>Proximity card reader</td>
<td>500</td>
<td>275</td>
<td>550</td>
<td>325</td>
</tr>
<tr>
<td>Coin/Token operated gate</td>
<td>150</td>
<td>100</td>
<td>200</td>
<td>125</td>
</tr>
<tr>
<td>Fixed fee to cashier – with gate</td>
<td>200</td>
<td>150</td>
<td>250</td>
<td>200</td>
</tr>
<tr>
<td>Fixed fee to cashier – no gate</td>
<td>250</td>
<td>200</td>
<td>350</td>
<td>275</td>
</tr>
<tr>
<td>No required stop</td>
<td>800</td>
<td>550</td>
<td>1,050</td>
<td>700</td>
</tr>
</tbody>
</table>

### Table 14-4 Typical Parking Control Service Rates per Lane

<table>
<thead>
<tr>
<th>Type of Control</th>
<th>Design Service Rate</th>
<th>Maximum Service Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EA(^*)</td>
<td>STU(^b)</td>
</tr>
<tr>
<td>Entrance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ticket dispenser – automatic</td>
<td>525</td>
<td>300</td>
</tr>
<tr>
<td>Ticket dispenser – push button</td>
<td>450</td>
<td>250</td>
</tr>
<tr>
<td>Ticket dispenser – machine read</td>
<td>375</td>
<td>200</td>
</tr>
<tr>
<td>Coded-card reader</td>
<td>350</td>
<td>225</td>
</tr>
<tr>
<td>Proximity card reader</td>
<td>500</td>
<td>275</td>
</tr>
<tr>
<td>Coin/Token operated gate</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Fixed fee to cashier – with gate</td>
<td>200</td>
<td>150</td>
</tr>
<tr>
<td>Fixed fee to cashier – no gate</td>
<td>250</td>
<td>200</td>
</tr>
<tr>
<td>Variable fee to cashier</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Validated/Pre-cashedier ticket</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Machine read ticket:</td>
<td>375</td>
<td>200</td>
</tr>
<tr>
<td>With manual license plate check</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>With camera license plate check</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>No required stop</td>
<td>375</td>
<td>250</td>
</tr>
</tbody>
</table>

* EA = Easy or straight approach to control service position.

* STU = Sharp turn within 100 feet of either side of the control position and/or patrons unfamiliar with facility.

* A 1991 study by Paul Box for ITE Committee 5PB-4 at Chicago O’Hare Airport parking garage found flow rates of 380 to 430 vph, confirming these values.

** The 1991 study by Paul Box also found exit flow rates of 120 vph.

Vehicle circulation on the site may be either two-way or one-way, depending on site dimensions and the angle of the parking stalls. Two-way circulation is generally allowed with 90-degree stalls, whereas one-way circulation is generally used with stall angles less than 90 degrees.

Cross aisles are necessary in large facilities to allow internal circulation. Generally, a parking row more than about 40 stalls long should have a cross aisle provided to reach exits or other parking stalls. In the ideal circulation pattern, an inbound driver is able to move in a continuous flow past all potentially available parking stalls. Upon unparking, the driver is able to reach the exit driveway while passing only a minimum number of other stalls. In practice, these conflicting needs are best addressed by location and proper design of cross aisles in parking lots. In large parking structures, “clearway” exit ramps (separate from parking aisles) are sometimes used to limit internal conflict during departure.

General Parking Dimensions

For the foreseeable future, a vehicle mix of widely varying sizes may be anticipated. From 1980 to 1986, the percentage of small cars sold in the United States increased from 52.7 to 56.0. As of 1995, the percentage had dropped to 35.4. If some mid-sized vehicles are excluded, the sale of larger cars dropped from 36.4 percent in 1980 to 22.2 percent in 1986, then rose to 32.0 percent in 1995. A market research group estimates that light trucks (vans, pick-ups, and sport utility vehicles) will account for 46 percent of all passenger car sales in the next few years. The variability in the trends must be considered.

In developing the design of any parking facility, it is customary to work with stalls, aisles, and combinations called “modules.” A complete module is one access aisle servicing a row of parking on each side of the aisle (see Figure 14–1). In some cases, partial modules are used where the aisle only serves a single one-side row of parking. This inefficient arrangement should be avoided where possible.

There are three ways of handling layout:

- design all stalls for large vehicles—about 1.8 m wide by 5.2 to 5.5 m long (6 ft wide by 17 to 18 ft long);

- design some stalls for large and some for small vehicles—about 1.5 m wide by 4.3 to 4.6 m long (5 ft wide by 14 or 15 ft long); or

- provide a composite layout with mid-size dimensions (too small for some large cars, and larger than needed for most for small cars).

The minimum practical stall width varies principally with turnover, experience of the parker, and vehicle size. Commercial parking attendants can park large cars in stalls less than 2.4 m (8.0 ft) wide. With self-parking, stall widths that will accommodate most passenger cars, vans, and light trucks range between 2.5 m and 2.7 m (8.3 ft and 8.8 ft), depending on anticipated parking activity. It is important to note that stall widths are measured perpendicular to vehicle length. If the stall is placed at an angle of less than 90 degrees, the width parallel to the aisle must be increased.

---

Figure 14–1 Dimensional Elements of Parking Layouts

Source: Adapted from R.A. Weant, Parking Garage Planning and Operation, Eno Foundation for Transportation, Inc., 1978, Fig. 20.

---

proportionately (see Figure 14–1). Site-specific circumstances will influence determinations of the most appropriate stall width dimension. For example, a generous stall width is suggested by conditions of high parking turnover, limited module width in which to develop the access aisle, or desire for a high level of user comfort and convenience. Where parking turnover is expected to be low, as for all-day employee parking, narrower stall widths are usually acceptable.

The length of stall should be appropriate to the overall length of most cars expected to use the space. The length refers to effective longitudinal dimension of the stall (but not necessarily the length of the stall line marking). When rotated to angles of less than 90 degrees, the stall depth perpendicular to the aisle increases up to 0.3 m (1 ft) and then decreases.

Most parking aisles serve for both circulation and access to stalls. Exceptions concern intermediate cross aisles, used to break up an otherwise excessive aisle length (generally more than 40 stalls long), or those at the ends of aisles. The access-aisle width required to allow single-pass parking and unparking maneuvers varies principally with the angle of parking (relating stall length to the perpendicular depth), and secondarily with the stall width. When dealing with large facilities, most parking designers work directly with the combinations of stall depth plus aisle width, or modules.

The total dimensions required for a parking module are produced by adding together the aisle width plus the stall depths (perpendicular to the aisle) on both sides. However, the effective stall depth depends on the boundary conditions of the module. If car bumpers contact a wall or fence on one or both sides, the maximum total module requirement is developed. If there is no boundary barrier of bumper height, but tires of parked cars contact wheel stops or curbing, the vehicle overhang must be considered. The curb must be set back if any bumper contact beyond the curb is critical. For 90-degree pull-in parking, the setback to the inner face (wheel side) of the curb should be about 0.8 m (2.5 ft). For back-in operation, a setback of curbing between 1.2 and 1.4 m (4.0 to 4.5 ft) is needed because of the greater rear overhang of some automobiles.

For parking at angles of less than 90 degrees, bumper overhangs beyond curbing are generally reduced with decreasing angle; for example, the front drops to less than 0.6 m (2 ft) and the rear about 1 m (3 ft) at 45-degree angles.

Back-in parking is generally the best (a narrower access-aisle width can be used) and potentially the safest (exit by pull-out rather than back-out, which greatly reduces the potential for striking other parked cars, moving vehicles, or pedestrians in the aisle). However, most drivers are unskilled in this maneuver and will resort to several pull up-and-back efforts to park in a stall that could be readily entered by a single backing operation. Although a significant number of commuter parkers (as at a rail station) may back into the parking stalls, aisle design for self-parkers is always based on a pull-in type of entry.

The above setback dimensions are not adequate to completely protect fences or decorative walls on the perimeter. Unusual overhangs may be found and it is also possible for tires to ride up on or over wheel stops or curbing. When positive limitation is required, a bumper contact barrier such as a structural wall or highway guardrail should be used at the end of the stall (see sections dealing with boundary protection in parking lots and garage design later in this chapter).

Another type of module, the interlock, is possible at angles below 90 degrees, as shown in Figure 14–1. The two types of interlocks are the bumper-to-bumper arrangement (the most common and preferable type) and the "nested" interlock (not illustrated). The nesting interlock, which can be used at 45 degrees, is produced by adjacent aisles having one-way movements in the same direction, but requires the bumper of one car to face the fender of another car. Wheel stops may be needed for each stall, and, even with their use, the probability of vehicular damage is much greater than for other parking arrangements. Furthermore, the wheel stops usually represent a trip-and-fall hazard.

**Parking Dimensions for Large Cars**

The long-term trend in American automobile design toward increased width apparently stopped before 1980. However, more efficient engines and increased use of light-weight materials may allow vehicle size to increase again. The practical limits needed for door-opening space between cars, as well as driver or passenger access to the vehicles, combine to produce an "optimum" stall width of about 2.6 m (8.5 ft) for most applications today, unless vehicles are segregated by general size. Widths exceeding 2.7 m (9 ft) are not recommended (except for stalls for vehicles used by persons with
Table 14–5  Stall Width Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Width (ft)*</th>
<th>Typical Turnover</th>
<th>Typical Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>A</td>
<td>9.00</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>8.75</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>8.50</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*For large-size vehicle, measured at right angles to stall.

1 ft = 0.305 m

Table 14–6  Large-Size Parking Layout Dimension Guidelines
(See Figure 14–1 for description of elements)

<table>
<thead>
<tr>
<th>Parking Class</th>
<th>Stall Width (ft)</th>
<th>Stall Width Parallel to Aisle (ft)</th>
<th>Stall Depth to Wall (ft)</th>
<th>Stall Depth to Interlock (ft)</th>
<th>Aisle Width (ft)</th>
<th>Wall to Wall (ft)</th>
<th>Interlock to Interlock (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic Modules</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Two-Way Aisle — 90 Degrees
| A             | 9.00             | 9.00                            | 17.5                     | 17.5                          | 26.0            | 61.0             | 61.0                        |
| B             | 8.75             | 8.75                            |                          |                               |                 |                  |                             |
| C             | 8.50             | 8.50                            |                          |                               |                 |                  |                             |
| D             | 8.25             | 8.25                            |                          |                               |                 |                  |                             |

Two-Way Aisle — 60 Degrees
| A             | 9.00             | 10.4                            | 18.0                     | 16.5                          | 26.0            | 62.0             | 59.0                        |
| B             | 8.75             | 10.1                            |                          |                               |                 |                  |                             |
| C             | 8.50             | 9.8                             |                          |                               |                 |                  |                             |
| D             | 8.25             | 9.5                             |                          |                               |                 |                  |                             |

One-Way Aisle — 75 Degrees
| A             | 9.00             | 9.3                             | 18.5                     | 17.5                          | 22.0            | 59.0             | 57.0                        |
| B             | 8.75             | 9.0                             |                          |                               |                 |                  |                             |
| C             | 8.50             | 8.8                             |                          |                               |                 |                  |                             |
| D             | 8.25             | 8.5                             |                          |                               |                 |                  |                             |

One-Way Aisle — 60 Degrees
| A             | 9.00             | 10.4                            | 18.0                     | 16.5                          | 18.0            | 54.0             | 51.0                        |
| B             | 8.75             | 10.1                            |                          |                               |                 |                  |                             |
| C             | 8.50             | 9.8                             |                          |                               |                 |                  |                             |
| D             | 8.25             | 9.5                             |                          |                               |                 |                  |                             |

One-Way Aisle — 45 Degrees
| A             | 9.00             | 12.7                            | 16.5                     | 14.5                          | 15.0            | 48.0             | 44.0                        |
| B             | 8.75             | 12.4                            |                          |                               |                 |                  |                             |
| C             | 8.50             | 12.0                            |                          |                               |                 |                  |                             |
| D             | 8.25             | 11.7                            |                          |                               |                 |                  |                             |

Notes: In general, these dimensions are subject to slight reductions by local agencies under high-cost conditions (such as garages) or slight increases in areas subject to special needs (such as extensive snowfall). Aisle width may be narrowed by about 1 ft without a major increase in congestion and accessibility of parking stalls (particularly in structures where high construction cost is a factor). A one-step trade-off can be made between stall and aisle width. A decrease of 2 ft in the module can be compensated for by a 0.5-ft increase in stall width for the appropriate class.

Column 1 — See Table 14–5 for typical uses (A for high turnover, B and C for medium turnover, and C and D for low turnover).
Columns 5, 8 — May also apply to boundary curb where bumper overhang is allowed.

Column 6 — To vehicle corner.
Columns 6 to 8 — Rounded to nearest foot.

1 ft = 0.305 m

disabilities), because of inefficiency—wasted land and pavement area, unnecessary added maintenance such as cleaning and lighting, decreased capacity for a given site, increased storm water runoff, and increased walking distances for users.

One approach to the range of stall-width needs is to consider a stall classification that relates width to type of use.\(^8\) This might be roughly equated to the level-of-service concept, whereby parking delay and ease of access and egress vary with expected activity and type of user. Table 14–5 identifies four stall width classes associated with typical turnover/user characteristics, for large vehicles 1.8 m wide by 5.2 to 5.5 m long (6 ft wide by 17 to 18 ft long).

Table 14–6 lists design dimension guidelines for large cars for typical parking angles, stall widths, and modules. In practice, a more rapid parking operation will be achieved if the dimensions are increased. Slight reductions are also feasible as given in the table notes.

Narrowed stall width in each class for parking angles of less than 90 degrees is not desirable. There is a relation between stall width and aisle width, as shown in Table 14–6, but the stall width needs are basically determined by door-opening clearances. Only at very flat angles of less than 35 degrees may doors open ahead or behind the cars in adjacent stalls, and even then there can be little reduction in basic stall width.

### Table 14–7 Small-Size Parking Layout Dimension Guidelines
(See Figure 14–1 for description of elements)

<table>
<thead>
<tr>
<th>Parking Class</th>
<th>2 - Sw</th>
<th>3 - WP</th>
<th>4 - WP(_h)</th>
<th>5 - WP(_l)</th>
<th>6 - AW</th>
<th>7 - W(_2)</th>
<th>8 - W(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic</td>
<td>Stall Width</td>
<td>Parallel to Aisle</td>
<td>Stall Depth to Wall</td>
<td>Stall Depth to Interlock</td>
<td>Aisle Width</td>
<td>Wall to Wall</td>
</tr>
<tr>
<td>Two-Way Aisle — 90 Degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/B</td>
<td>8.0</td>
<td>8.0</td>
<td>15.0</td>
<td>15.0</td>
<td>21.0</td>
<td>51.0</td>
<td>51.0</td>
</tr>
<tr>
<td>C/D</td>
<td>7.5</td>
<td>7.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-Way Aisle — 60 Degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/B</td>
<td>8.0</td>
<td>9.3</td>
<td>15.4</td>
<td>14.0</td>
<td>21.0</td>
<td>52.0</td>
<td>50.0</td>
</tr>
<tr>
<td>C/D</td>
<td>7.5</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-Way Aisle — 75 Degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/B</td>
<td>8.0</td>
<td>8.3</td>
<td>16.0</td>
<td>15.1</td>
<td>17.0</td>
<td>49.0</td>
<td>47.0</td>
</tr>
<tr>
<td>C/D</td>
<td>7.5</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-Way Aisle — 60 Degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/B</td>
<td>8.0</td>
<td>9.3</td>
<td>15.4</td>
<td>14.0</td>
<td>15.0</td>
<td>46.0</td>
<td>43.0</td>
</tr>
<tr>
<td>C/D</td>
<td>7.5</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-Way Aisle — 45 Degrees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/B</td>
<td>8.0</td>
<td>11.3</td>
<td>14.2</td>
<td>12.3</td>
<td>13.0</td>
<td>42.0</td>
<td>38.0</td>
</tr>
<tr>
<td>C/D</td>
<td>7.5</td>
<td>10.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Column 1 — See Table 14-5 for typical uses (A for high turnover, B and C for medium turnover, and C and D for low turnover).

Columns 5, 8 — May also apply to boundary curb where bumper overhang is allowed.

Column 6 — To vehicle corner.

Columns 6 to 8 — Rounded to nearest foot.

1 ft = 0.305 m

Source: ITE Technical Council Committee 5D-8, Guidelines for Parking Facility Location and Design.

Parking Dimensions for Small Cars

Special dimensions for small-car parking have application in the United States. The percentage of such cars varies by year and also somewhat by geographical location. The small vehicle is about 1.5 m wide by 4.3 m to 4.6 m long (5 ft wide by 14 ft to 15 ft long). A suitable stall length for small cars is 4.6 m (15 ft). Stall widths of 2.3 m (7.5 ft) are appropriate for typical uses, and 2.4 m (8.0 ft) for higher turnover conditions. Table 14–7 gives several layout dimensions for small vehicles.

Composite Parking Dimensions

It would, of course, be highly desirable to use one standardized set of parking dimensions because problems exist in separating small and large cars. The smaller parking facilities probably do not warrant any consideration of separate dimensions for different-size vehicles. In some developments, it will be impractical to provide separate size layouts.

An “ideal” design would use the values in Table 14–6. However, this will result in more area used per average car stall than necessary. For this reason, composite dimensions have been proposed that represent a compromise between those necessary to adequately accommodate large vehicles and those needed for the small size. These rationalized dimensions would be based on the expected proportions (weighted averages) of large versus small vehicles. Although this concept unquestionably optimizes space needed to space provided, it also penalizes the drivers of larger cars. The net effects may be increased maneuvering to enter and leave the stall (hence possible added delay to other motorists using the access aisle), inability to open car doors a sufficient distance to comfortably enter or leave (increasing the potential for door-denting) and even complete denial of access to some stalls where adjacent vehicles are parked out of center.

Because of minimum car-door opening clearances, composite-size stalls should not reflect any narrower stall widths than the 2.5 m (8.25 ft) minimum given in Table 14–6. However, the aisle width in this table may be narrowed by 0.3 m (1 ft) or so without experiencing a major increase in congestion and accessibility of parking stalls. This would particularly apply in structures with high construction cost.

![Figure 14–2 Parking Layouts Combining Small and Large Car Stalls](image)

1 ft = 0.305 m

Source: ITE Technical Council Committee 5D-8, Guidelines for Parking Facility Location and Design.

PARKING AND TERMINALS 539
Small-Car Separation Techniques

Greater use of smaller cars in North America and pressure to make parking more space-efficient have resulted in a variety of parking arrangements to take advantage of smaller car sizes. The objective of each layout is to maximize the number of stalls in a given area. These designs may involve the provision of some stalls designed for the exclusive use of small cars, plus other stalls for large cars. Several alternative layouts are possible. These are illustrated in Figure 14-2, and reviewed in detail in the Guidelines for Parking Facility Location and Design. The effectiveness of segregating parking in this manner is dependent on real or perceived enforcement.

Stalls for People with Disabilities (Handicapped Stalls)

Handicapped parking stalls should be located close to elevators, ramps, walkways, and building entrances, with special consideration to access by persons in wheelchairs. Curb cuts should be at least 1.2 m (4 ft) wide to accommodate wheelchair users. Curb cuts and ramp surfaces at right angles to the main walk have been found to be hazardous for pedestrians using the walk. Many people have been injured by slipping or stumbling on steep cross slopes. To avoid this, cross slopes (slopes in the longitudinal direction of the walk) should not have a slope of more than 1 in 10 and preferably 1 in 12. (The Uniform Federal Accessibility Standards and Americans with Disabilities Act Accessibility Guidelines will allow a maximum slope of 1 in 8 where a flatter slope is not possible.) The areas of slope should be painted with a non-slip yellow coating.

An area 3.6 m (12 ft) wide is the minimum to provide adequate space to park a vehicle and allow the driver or passenger to operate a wheelchair between parked vehicles. A narrower width of 3 m (10 ft) is adequate where one side of the stall is open, such as at the end of a parking row when unobstructed adjacent pavement or a walking area is available. By either pulling or backing in, the driver or passenger of the vehicle can have access toward the clear side, provided a 90-degree parking layout is used. Handicapped stalls should not be located on grades sloping more than 5 percent in one direction or 2 percent in the cross-direction.

Each handicapped parking stall should be marked with a sign. Painting the wheelchair symbol on the pavement is also common. Further details and suggested layouts are addressed in Guidelines for Parking Facility Location and Design.

Federal, state and local laws vary, both in design and in arbitrary numbers of stalls required. However, a rational method of determining the number of stalls actually needed for typical land uses was developed by ITE Committee 5D-8 and published in the ITE Journal.

Special-Purpose Vehicles

The basic design principles discussed above relate to conventional vehicles of passenger-car size. This section reviews parking elements for other vehicle types such as trucks, buses, light trucks, motorcycles, scooters, mopeds, and bicycles.

Trucks

In general, trucks use the same entrances to most sites as do employee vehicles and other traffic. The entrances and exits must be designed to accommodate the largest expected truck. If parking is allowed at the curb near the driveway on the approach street, the vehicle path will be moved farther from the curb and result in a decreased entrance width and flare length. Adjustment of the property line location will also change the entrance dimensions. Ease of turning into the site

---

9 Ibid.
12 ITE, Guidelines for Parking Facility Location and Design.
14 ITE, Guidelines for Driveway Location and Design.
### Physical Design Layout of Loading Spaces

- **Design vehicle**
- **Length in feet (L)**
- **Dock angle (α)**
- **Clearance in feet (D)**
- **Berth width in feet (W)**
- **Apron space in feet (A)**
- **Total offset in feet (T)**

<table>
<thead>
<tr>
<th>Design Vehicle</th>
<th>Length in feet</th>
<th>Dock Angle (α)</th>
<th>Clearance in feet</th>
<th>Berth Width in feet</th>
<th>Apron Space in feet</th>
<th>Total Offset in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB-40</td>
<td>50</td>
<td>90°</td>
<td>50</td>
<td>10</td>
<td>63</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>60°</td>
<td>44</td>
<td></td>
<td>12</td>
<td>56</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>45°</td>
<td>36</td>
<td></td>
<td>14</td>
<td>52</td>
<td>102</td>
</tr>
<tr>
<td>WB-50</td>
<td>55</td>
<td>90°</td>
<td>55</td>
<td>10</td>
<td>72</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>60°</td>
<td>48</td>
<td></td>
<td>12</td>
<td>67</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>45°</td>
<td>39</td>
<td></td>
<td>14</td>
<td>55</td>
<td>103</td>
</tr>
</tbody>
</table>

1 ft = 0.305 m

may be accomplished by use of "Y" or angle approaches. This may be particularly useful for access to and from a one-way street.

The minimum width of driveway required at security gates is generally recommended at 4.9 m (16 ft) for one-way operation, 8.5 m (28 ft) for two-way operation, and 10.4 m (34 ft) where pedestrian traffic is involved and no separate walkway is provided. If inbound trucks are stopped at the gate, it will be necessary to recess the gates so that sufficient storage space will be available for one, and preferably two trucks, without backup into the access street. High-volume locations will need special evaluation with regard to numbers of gates and reservoir area.

Service roads within the property should be at least 7.3 m (24 ft) wide for two-way operation. Wherever practical, truck traffic should circulate counterclockwise, as the left turn is easier with large commercial vehicles because the driver's position is on the left side of the vehicle. Also, this places the truck in the most favorable position for backing into the dock. Parking should be prohibited where it may conflict with truck circulation or maneuvering.

There are four major elements to consider in the design of a loading dock: vertical clearance, depth (length), width, and apron space. These are illustrated in Figure 14–3, which also gives suggested design values for several layouts and dock widths. The type and size of truck is the most critical factor in dock design. For suburban developments, the type of land use gives an indication of truck sizes requiring accommodation. In a CBD, the average truck size is likely to be smaller, because of more constricted access. Table 14–8 gives the results of a Dallas study.

Because vehicle design is not standardized, no single dock height can satisfactorily accommodate all vehicles. One approach is to provide several different dock heights, basing the design on the expected distribution of delivery vehicles. Another approach is to provide one continuous dock height to serve all vehicles, recognizing the possible need to provide some type of adjustable dock-height equipment.

Table 14–9 suggests dimensions for truck docks to serve the three general sizes of vehicles in use today. The vertical clearances used should be provided throughout the access route. If several different truck sizes are expected (this is usually the case), then different dock lengths may be provided, based on the frequency of use by truck size. The width of the loading space should consider needed clearances between trucks (some are side-loading). In other cases, smaller delivery vehicles may, in peak periods, double-park in front of trucks backed up to the dock. Space for handcart movement between trucks is thus desirable.

The total maneuver area (apron plus length of truck) required in front of docks depends on the overall length of trucks, the turning radii, direction of traffic circulation, angle of dock, and the width of berths. For a 90-degree dock, a length from the edge of the loading dock of not less than twice the overall length of the longest vehicle using the facility has been recommended. This is because tractors could still be attached to the docked trailer. Interpreting a recent study using a typical WB-50 design vehicle 19.8 m (65 ft) long with a 14.6-m (48-ft) trailer confirms the recommendation.

Where sufficient maneuver space is not available for trucks to use docks parallel to the building wall, a sawtooth arrangement may be used as illustrated in Figure 14–3. The number of berths that may be accommodated in a given dock

---

**Table 14–8 Distribution of Delivery Vehicle Types – Dallas Central Business District**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Percentage of Total Shipment Carried</th>
<th>Cumulative Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger car</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Pickup truck</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Van</td>
<td>27</td>
<td>55</td>
</tr>
<tr>
<td>Single-unit truck</td>
<td>40</td>
<td>95</td>
</tr>
<tr>
<td>Tractor-trailer truck</td>
<td>3</td>
<td>98</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>


---

length will be less with angular or sawtooth berths than with trucks at 90 degrees. Berths at angles of 30 degrees or less use twice as much dock space as do those at 90 degrees. Truck circulation must be one-way for backing into the berth. Wherever possible, circulation should be counterclockwise to avoid blind backing maneuvers.

Many docks face flush with the outside wall of the building. This type of dock can offer a covered, heated, closed-dock operation without enclosing the trucks. A totally enclosed dock includes the maneuver area; trucks pull into the area, back into the dock space, and generally leave by another door. A second type of enclosed dock does not enclose the maneuver space, and trucks back through a door and straight into the loading dock. Care must be taken to eliminate the accumulation of vehicle exhausts in the enclosed area. However, enclosed docks have the advantage of protecting goods, controlling pilferage, providing the ability to erect mechanical systems for loading and unloading of open trucks, and protection from weather.

Modern industrial construction has often eliminated basements and dock-level buildings. Depressed approaches to docks can be used to create the elevation differential needed for the loading-unloading operation. These grades on the approach should not exceed 10 percent. With a depressed approach, the top of the truck may contact the building wall before the truck bed contacts the bumpers if the dock is flush with the wall. To avoid this, the approach grade can be lessened, the building wall recessed, or the dock face extended. Another solution is to provide a level section 4.6 to 7.6 m (15 to 25 ft) long immediately adjacent to the dock, at the bottom of the approach grade (long enough to accommodate a design truck).

A waiting or holding area is required next to the docks to accommodate trucks waiting for a dock space. The size of this area should be sufficient to provide space for the maximum number of trucks expected on the site, less the number of dock spaces provided.

**Buses**

Guidelines by the American Association of State Highway and Transportation Officials (AASHTO) use a bus design vehicle 12.2 m (40 ft) long (which fits the typical 47-passenger tour bus dimension) and a width of 2.6 m (8.5 ft). This results in an outer swept-path radius of 12.8 m (42 ft). Use of a similar dimension for school bus access is suggested. Typical school bus lengths range from about 6.1 m (20 ft), accommodating 20 to 24 passengers; to about 10.7 m (35 ft), accommodating 55 to 66 passengers. Typical width is 2.4 m (8 ft). Parking-stall length should reflect the bus size to be stored. A stall width of 3.3 or 3.6 m (11 or 12 ft) is appropriate. While legal bus heights of 4.1 m (13.5 ft) apply in most states, some may allow 4.3 m (14 ft).

**Pick-Ups, Sport Utility Vehicles, and Vans (Light Trucks)**

Pick-up trucks, sport utility vehicles, and vans range from about 5 to over 5.5 m long (16.5 to 18 ft) with turning radii of about 7.3 m (24 ft). Typical widths are about 1.7 to 2 m (5.6 to 6.6 ft). Parking-stall dimensions of 2.7 by 5.5 m (9 by 18 ft) are suggested for design purposes. Full-size pick-up trucks are readily parked in Class A stalls (see Table 14–5). They are frequently found in shopping centers, particularly in rural and suburban areas.

Manufacturers also provide a larger “light” truck on a modified frame used for pick-ups and vans. By adding dual wheels on the rear axle, a pick-up truck can be 2.4 m (8 ft) wide. Trucks of this type are sometimes parked in Class A stalls, causing problems in adjacent stalls.

---

By extending the frame with a dual rear wheel, the light truck with flatbed, dump, or cube body has similar dimensions to the AASHTO single-unit truck. Most trucks of this type are for commercial use and not usually parked in Class A stalls of shopping centers, offices, and the like.

Recreational Vehicles

The AASHTO Design Motor Home measures 2.4 by 9.1 m (8 by 30 ft), has a 6.1 m (20 ft) wheelbase, and an outer offset-tracking radius of about 12.1 m (40 ft).20 These dimensions greatly exceed those of the more common conversion vans, (which generally fit within a Class A stall).

While some motor homes will be parked in public lots, such as at shopping centers, special areas set aside for their use are generally not warranted. Exceptions include roadside rest areas, amusement parks, and other vacation-oriented developments.

Motorcycles, Scooters, and Mopeds

Typical motorcycles in use today have wheelbases of about 1.4 to 1.5 m (4.5 to 5 ft), with overall lengths of about 2.3 m (7.5 ft). While extended fork and heavy touring cycles may reach slightly over 2.4 m (8 ft), the use of a 2.4 m stall length will accommodate the vast majority of motorcycles. Handlebar widths typically do not exceed 86 cm (34 in), and cycles can readily be parked in 1.5 m (5 ft) wide stalls. A 3 m (10 ft) aisle width is ample.

Motor scooter wheelbases typically range from about 1.1 to 1.2 m (3.5 to 4 ft) (although one model exceeds 1.5 m [5 ft]). A 1.8-m (6-ft) stall length will accommodate most scooters, as will 1.2 m (4 ft) wide stalls with 1.8 m (6 ft) access aisles.

Mopeds and motorized bikes are roughly similar in size—about 1.8 m (6 ft) overall length and 46 to 69 cm (18 to 27 in) wide. A stall width of .9 to 1.2 m (3 to 4 ft) is needed, with a length of 1.8 m (6 ft) and an access aisle also about 1.8 m (6 ft) wide.

Lockers are available for secured and weather-protected moped parking. One two-unit lock is 1.2 m (4 ft) wide and slightly over 1.8 m (6 ft) long. However it requires each vehicle to be backed in (on opposite sides), thus requiring access aisles on both sides of the locker. Another device is a vertical stand and heavy chain, arranged to allow recessing of the padlock so that it is not accessible to bolt-cutters.

Bicycles

Bicycles typically measure 1.6 to 1.8 m (5.5 to 6 ft) in length, with handle bars spanning about 43 to 69 cm (17 to 27 in). A very broad selection of parking racks, posts, and lockers have been manufactured. For basic layout, a 0.6 m wide by 1.8 m long stall (2 by 6 ft) is appropriate, served by a 1.5 m (5 ft) wide aisle.

Bicycles are quite vulnerable to theft, since many owner-supplied locks, cables, or chains can be cut with bolt-cutters in a few seconds and bicycle accessories are easily vandalized. The primary problem in bicycle parking is security. Using this measure, three classes of bicycle parking devices have been established:

- Class I: Lockers or controlled access areas where bicycles may be stored, protected from theft, weather, and vandalism.
- Class II: Devices which lock the bicycle frame and wheels. The individual may have to provide a padlock.
- Class III: Bicycle racks or fixed objects to which a bicycle may be secured by the individual’s own locking device.

---

Storage systems range from completely enclosing the bicycle within a locker (Class I), to securing both wheels and the frame in units holding one or two bikes (Class II). Controlled access areas that provide protection from weather and vandalism also constitute a high security, Class I facility. Strong, U-shaped locks supplied by the user are another effective means of securing bicycles, whether used in conjunction with a conventional rack or by attaching them to informal stationary objects. These locks are not as vulnerable to bolt cutters as conventional cables or chains.

State-of-the-art (Class III) devices should support the bicycle in a stable and upright manner so if bumped, it would not roll or fall down. They should match the refined technology of the bicycle itself. The traditional bicycle “pipe” or “dish” rack should not be considered as a Class III device. By the nature of their design, they may bend wheel rims and damage gearing mechanisms of multi-speed bicycles, should the bikes fall over while chained to them.

The location of bicycle parking equipment on a site is as important as the technology itself. If bicycle parking is located in an automobile parking lot, physical barriers are needed to separate the parking areas. Even at very slow speeds a car can do extensive damage to a bicycle that is firmly attached to a fixed parking device. An isolated location can lead to tampering or give the thief a chance to defeat the locks undetected. Parking should be near the building entrance and visually surveyed where possible. Combinations of equipment and location can enhance the security of bicycle parking. For example, Class II equipment located near an attendant in a parking garage is equivalent to Class I bicycle lockers. Problems relating to the use of bike parking may arise if bicyclists are unaware that parking is available or if they cannot find it at a given site. Publicity of location and simplicity of operation are important.

Time of use is another factor. Personal business and shopping visits have a lower security requirement, compared to all-day commuter or student bike parking that may also have night-time use.

Stall Markings

Unless markings are used, parking will be difficult to enforce, and inefficient use of the area will result. Markings typically require some type of permanent surfacing. A paved surface has advantages in allowing proper drainage, reducing dust, facilitating snow removal and sweeping, providing an improved walking surface, reducing maintenance cost, and presenting a more pleasing appearance.

White is the standard color for marking stall lines, in most communities, with yellow used only to delineate areas of NO PARKING. Yellow cross-hatching is most effective, for example, if other lines are white.

Striping lines are normally about 10 cm (4 in) wide. Many owners have painted double lines between stalls and are of the opinion that this causes drivers to center their cars better within each stall. However, a study of 14 sites (shopping, motels, airport, offices) in three states, encompassing 6,800 parking stalls, found no reduction in the proportion of vehicles encroaching against or into the adjacent stalls, where double lines were used, as compared with single lines.21 At all but two sites, there was more encroachment with the double lines.

Some liability issues need to be recognized. Paint can become slippery when wet. While not usually a problem with ordinary stall lines, wider stop bars or crosswalk lines may pose a problem if on a significant grade. This can be treated by use of abrasives mixed into the paint. Plastic ‘buttons’ have been used to delineate parking stalls at a few locations. These devices form pavement irregularities and can be a trip-and-fall hazard along direct pedestrian paths to enter or leave from parked vehicles.

Parking Row Sidewalks and Barriers

Raised pedestrian sidewalks are sometimes used in large parking lots to separate rows of cars and to provide more favorable walking conditions. People walking to and from cars most often use the aisles, however, and the value of interior walkways is so debatable that these are seldom used today.

Some operators erect ropes or cables down module limit lines to prevent drivers from pulling across into the adjacent aisle. However, a study of parking lot accidents found only one percent to involve vehicles cutting across parking rows. Most of these few were sideswipes of parked vehicles—no different from similar parking/unparking collisions. Ropes or cables interfere with pedestrian access and can create a hazard to both pedestrians and bicyclists. Their use is not recommended.

Liability Issues

Many lawsuits allege defects in parking lots. These occur in two general categories: (1) pedestrian falls, and (2) vehicle collisions, including fixed objects and pedestrians. Issues relate to design, operation, or maintenance. The following lists include elements typical of claims that have been made in the United States. They are arranged in three groups: pedestrian slip or trip-and-fall hazards, vehicle hazards, and hazards common to both collisions and falls.

Pedestrian slip or trip-and-fall hazards include the following:

- Wheel stops located in direct pedestrian paths, creating a trip-and-fall hazard.
- Side slopes of handicapped ramps placed along sidewalks, where the slope ratio exceeds the desirable one in ten and/or where the surface has not been painted with a yellow, skid resistant surface.
- Inadequate lighting to allow view of surface defects such as holes or cracks or other fixed objects, as well as for personal security issues.
- Inadequate drainage and depressions which can retain water and freeze into ice in northern climates.
- Barriers between parking modules, such as ropes or cables, creating hazards for pedestrians or bicycle riders.
- Lack of building entrance crosswalks painted across building frontage roadways where pedestrian concentrations occur.
- Islands at the ends of parking rows extending out beyond the typical vehicle length, forming an added trip-and-fall hazard.
- Inadequate boundary controls or setbacks to prevent vehicle bumper overhang across public sidewalks adjacent to the site, which can be a hazard to pedestrians.
- Use of paint which can become slippery when wet—especially on sloping surfaces.
- Lack of contrast between walk surfaces or edges of steps and adjacent pavement to give pedestrians notice of a step down.
- Use of “buttons” instead of paint to form parking stall lines.
- Stairways in garages.
- Inadequate maintenance to keep surface clean of trash, excessive oil drips, snow, and ice.

Collision hazards to drivers of vehicles include the following:

- Lack of reflectorization of traffic control devices.

---

• Inadequate reflective marking for night visibility of fixed objects such as fire hydrants, utility poles, light pole bases or sign posts in the driving path.

• Lack of traffic controls at major driveways intersecting access streets, such as the need for traffic signals where warrants are met.

• Substandard driveway radii, causing vehicle encroachment inside a facility or excessive slowing down to enter site.

• Lack of separate left turn lanes at major driveway entry points.

• Lack of proper internal traffic control devices to regulate major conflicting flows.

• Inadequate boundary controls adjacent to abrupt drop-offs as needed to reasonably restrain vehicles.

• Lack of end islands to open up sight distance at parking row intersections in larger facilities such as at ring roads in shopping centers.

• Inadequate maintenance of traffic controls: signs, signals, pavement markings.

Hazards common to both collisions and falls include the following:

• Sight obstructions at driveways or aisle intersections formed by bushes, low-growing trees, ground-mounted signs, or building walls.

• Speed bumps creating both a vehicular hazard and a pedestrian trip-and-fall condition.

• Yellow stall markings instead of white, which depreciate the value of yellow when used to mark curbing, steps, or fixed-object hazards.

• Inadequate maintenance of lighting components.

These issues are addressed and typical desirable treatments (where not otherwise covered in this chapter) are given in two 1994 papers.\textsuperscript{23,24} The ITE \textit{Guidelines for Driveway Location and Design} provides recommended access dimensions.\textsuperscript{25} One study of parking lot accidents found the rate for 90-degree parking in medium and high turnover lots to be much lower than for 45 and 60 degree layouts, although the difference in angles is not known to have precipitated a specific lawsuit.\textsuperscript{26}

**Parking Lots: Special Elements and Layout Alternatives**

Most of the design principles apply to all parking lots. While a “lot” is a single surface facility without any structural cover, in hilly terrain it may be built on adjacent levels in a stepped or terraced fashion, with short ramps to connect the different levels. Because of their lack of walls or cover, parking lots have no ventilation problems and lighting is sometimes provided by relatively tall poles, thus affording high efficiencies and minimizing the number of poles. Generally, lots have clear sight lines and offer a feeling of greater security than does a more confined space. Lots are not restricted on vehicle heights and thus afford access to both commercial and emergency vehicles.

Most parking facilities are of the surface-lot variety because of relatively low costs, coupled with ease and speed of design and construction. They are intrinsically more efficient per stall than parking in structures, because there are no requirements for ramps, stairs, elevators, or structural columns. It is often possible to use more generous dimensions for stall and aisle widths in lots, as compared with structures, because of lower construction costs.


\textsuperscript{25} ITE, \textit{Guidelines for Driveway Location and Design}.

\textsuperscript{26} Box, “Parking Lot Accident Characteristics.”
Land cost generally is the determining factor when considering parking on the surface versus a structure. The trend to have most parking in lots, except in central areas, is expected to continue into the foreseeable future.

Generally, the layout of a parking lot seeks to strike a balance to maximize capacity, maneuverability, and circulation. Rectangular sites afford the greatest opportunity to balance these factors. Arranging parking stalls along both sides of access aisles, with aisles parallel to the longer site dimension, provides greatest space efficiency. However, this is not always possible or desirable. The most appropriate layout depends on site-specific conditions. For two-way traffic, 90-degree parking is generally used. Often this is the most efficient layout if the lot size and shape are appropriate. Furthermore, the wide aisles are more inviting than the narrower ones used for space economy in flatter-angle layouts.

Much of the alleged difficulty with 90-degree parking has stemmed from inadequate aisle dimensions. Where proper measurements are used, a smooth and efficient operation can be achieved. The general advantages of 90-degree parking, as compared with lesser angles, are as follows:

- This type of parking is the most common and understandable.
- 90-degree parking can sometimes be better fitted into buildings (see section on garage design later in this chapter).
- 90-degree parking is generally most efficient if the site is sufficiently large.
- Two-way movement is used, which can allow short, dead-end aisles.
- Unparking can be accomplished in either direction, minimizing travel distance and internal conflict.
- 90-degree parking does not require aisle directional signs or markings.
- Wide aisles can provide room to pass stopped vehicles waiting for an unparking vehicle.
- Wide aisles increase separation between pedestrians walking in the aisle and moving vehicles.
- Wide aisles increase clearance from other traffic in the aisle, during unparking maneuvers.
- 90-degree parking results in fewer total aisles, which makes locating a parked vehicle easier.

Several advantages of angle parking (usually 45 to 75 degrees), include the following:

- This type of parking is the easiest in which to park.
- It can be adapted to almost any width of site by varying the angle.
- It requires slightly deeper stalls but much narrower aisles and modules.

Disadvantages include the following:

- Drivers must unpark and proceed in original direction, hence producing greater out-of-way travel and conflict.
- Unused triangles at end of parking aisles reduce overall efficiency.
- Additional cross aisles for one-way travel are required to avoid long travel, which adds to gross area used per parking stall.
- It is difficult to sign one-way aisles.

The relative efficiencies of various parking angles may be compared by the number of square feet required per car stall (including the prorated area of the access aisle and entrances). Where the size and shape of the tract is appropriate, both
the 90-degree and 75-degree parking layouts tend to require the smallest area per car stall. In typical lot layouts for large vehicles, the average overall area required (including cross aisles and entrances) ranges between 28.8 and 30.7 m² (310 and 330 sq ft) per car. A very flat angle layout (such as 30 degrees) is significantly less efficient than other angles.

Many conditions exist where one-way aisles are desirable. With angles of less than 90 degrees, drivers can be restricted to certain directions; however, the angle should usually be no greater than 75 degrees to avoid drivers going the wrong way. Adjacent aisles generally have opposite driving directions. Any multiple of modules can be used, depending on location of entrances and exits and the size of available land. However, at angles below 45 degrees and with interlocking stalls, the module dimension may become too small to allow U-turn access between adjacent aisles by large cars.

Although the most efficient arrangement is usually found with aisles parallel to the long dimension of the site, parking aisles serving a specific generator should usually be oriented toward the building and/or pedestrian access points.

Access, Fee Collection, and Reservoir Areas

Entrances and exits at opposite ends of a parking lot tend to reduce conflicts between incoming and outgoing cars, but complicate revenue control. At entrances, care should be exercised to prevent backups onto the street. A well-designed parking lot often can accept arriving cars as quickly as the street system delivers them. Aside from acceptance rate limitations caused by revenue control measures, the principal causes of entry delay are sidewalk conflict with pedestrians, parking or unparking maneuvers just inside the entrance, and conflicting internal circulation, including vehicles waiting to exit.

Because driveway entrances to surface parking lots are at the same grade as the public sidewalks, it is generally impossible to avoid pedestrian conflict. The problem can sometimes be minimized by locating driveways on streets having lower pedestrian volumes and at points upstream from the heaviest pedestrian flow.

It is good practice to limit the number of stalls so close to the entrance that unparking maneuvers would require backing onto the sidewalk. Depending on the size and turnover of the facility, several stalls near the entrance may best be kept out of active (high-turnover) use; however, this is more of an operational than a design element.

Where a fee is charged, collection can involve on-site cashiering, monthly stickers, or parking meters. Smaller lots may use coin-operated gates (sometimes with payment required on both entry and exit). Another method uses a currency slot box, keyed to each numbered parking stall, as shown in Figure 14-4. Other methods include coin or currency-operated, or debit/credit card-operated ticket dispensers.

If parking meters are used, care must be taken to locate the mounting posts where they are least subject to vehicular damage. When set back behind curbs, a twin-meter post is placed in projection of the alternate parking stall lines. When used inside lots, quad-meter mounts can often be attached to a post set in a raised (bumper high) concrete base and located at the junction point of four adjacent stalls.

Parking lot operators that charge an hourly or daily fee often control revenue by issuing tickets at the entrance. If a ticket-dispensing machine is used, at least a two-space reservoir within the lot is usually needed. If tickets are manually dispensed from a booth, a larger inbound reservoir may be needed; however, this is highly dependent on the size (capacity) of the lot and its parker characteristics. Unfortunately, some smaller, high-turnover self-parking lots have a multipurpose cashier booth and entry gate located adjacent to the public walk. The one-space reservoir in this design is often inadequate to prevent backup into the street.

Where parking is done by attendants, a large inbound reservoir area may be needed. Adequate reservoir area is seldom found, and congestion with backups into the street are common experiences.

The reservoir requirements for access in and out of lots serving major traffic generators are usually based on traffic signal control of the driveway intersection. This is discussed in the section on major generators.