CHAPTER 3
MODAL CHARACTERISTICS

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1. INTRODUCTION

VOLUME 1: CONCEPTS
1. HCM User's Guide
2. Applications
3. **Modal Characteristics**
4. Traffic Operations and Capacity Concepts
5. Quality and Level-of-Service Concepts
6. HCM and Alternative Analysis Tools
7. Interpreting HCM and Alternative Tool Results
8. HCM Primer
9. Glossary and Symbols

OVERVIEW

Roadways serve users of many different modes: motorists, truck operators, pedestrians, bicyclists, and transit passengers. The roadway right-of-way is allocated among the modes through the provision of facilities that ideally serve each mode's needs. However, in many urban situations, the right-of-way is constrained by adjacent land development, which causes transportation engineers and planners to consider trade-offs in allocation of the right-of-way. Interactions among the modes that result from different right-of-way allocations are important to consider in analyzing a roadway, and the *Highway Capacity Manual* (HCM) provides tools for assessing these interactions. Local policies and design standards relating to roadway functional classifications are other sources of guidance on the allocation of right-of-way; safety and operational concerns should also be addressed.

CHAPTER ORGANIZATION

Chapter 3 introduces some basic characteristics of the travel modes addressed by the HCM. The following characteristics are considered in this chapter for each mode:

- Factors that contribute to a traveler's experience during a trip,
- Observed seasonal and daily variations in travel demand,
- Types of transportation facilities used by a given mode, and
- The interactions that occur between modes.

Chapters 4 and 5 continue the discussion of multimodal performance. Chapter 4 discusses traffic operations and capacity concepts and provides operational performance measures for each mode. Chapter 5 discusses quality and level-of-service (LOS) concepts and introduces the service measures for each mode that the HCM uses to assess transportation facilities from a traveler point of view.

Connected and Autonomous Vehicles

Connected Vehicles

Connected vehicles are vehicles with the capability of identifying threats and hazards on the roadway and communicating this information over wireless networks to other vehicles as well as the traffic management center to give drivers alerts and warnings. Connected vehicles use advanced wireless communications, onboard computer processing, advanced vehicle sensors, GPS navigation, and smart infrastructure, among other technologies. The connected vehicle concept is still evolving and has not yet been put into widespread practice in the United States. Current understanding of the concept suggests that connected vehicles should improve the speed of detection and response to congestion-causing incidents and reduce crashes, thereby improving travel time reliability (*5*).

Autonomous Vehicles

Autonomous vehicles are self-driving vehicles. They are distinct from connected vehicles in that autonomous vehicles cut the driver out of the routine driving process—either through assisted automation, under which the driver can choose to use automated control of specific features, or through full automation, with no control by the driver under normal circumstances. The vehicles can detect their environment and navigate their way through that environment. A few states have established laws and regulations for testing of autonomous vehicles on public streets by manufacturers. Autonomous vehicles could reduce reaction times and enable closer car following distances, which would facilitate higher densities of traffic and potentially higher capacities. They may also improve travel time reliability by reducing crashes (*6*).

Driver Characteristics (Human Factors)

Driving is a complex task involving a variety of skills. The most important skills are taking in and processing information and making quick decisions on the basis of this information. Driver tasks are grouped into three main categories: control, guidance, and navigation. Control involves the driver's interaction with the vehicle in terms of speed and direction (accelerating, braking, and steering). Guidance refers to maintaining a safe path and keeping the vehicle in the proper lane. Navigation means planning and executing a trip.

The way in which drivers perceive and process information is important. About 90% of information is presented to drivers visually. The speed at which drivers process information is significant in their successful use of the information. One parameter used to quantify the speed at which drivers process information is perception–reaction time, which represents how quickly drivers can respond to an emergency situation. Another parameter—sight distance—is directly associated with reaction time. There are three types of sight distance: stopping, passing, and decision. Sight distance helps determine appropriate geometric features of transportation facilities. Acceptance of gaps in traffic streams is associated with driver perception and influences the capacity and delay of movements at unsignalized intersections.

Factors such as nighttime driving, fatigue, distracted driving (e.g., using a mobile phone or in-vehicle technology), driving under the influence of alcohol and drugs, the age and health of drivers, and police enforcement also contribute to driver behavior on a transportation facility. All these factors can affect the operational parameters of speed, delay, and density. However, unless otherwise specified, HCM methods assume base conditions of daylight, dry pavement, typical drivers, and so forth as a starting point for analyses.

Base conditions are discussed generally in Chapter 4 and specifically in chapters in Volumes 2 and 3.

VARIATIONS IN DEMAND

The traffic volume counted at a given location on a given day is not necessarily reflective of the amount of traffic (*a*) that would be counted on another day or (*b*) that would be counted if an upstream bottleneck was removed. Traffic demand varies seasonally, by day of the week (e.g., weekdays versus weekends), and by hour of the day, as trip purposes and the number of persons desiring to travel fluctuate. Bottlenecks—locations where the capacity provided is insufficient to meet the demand over a given period of time—constrain the observed volume to the portion of the demand that can be served by the bottleneck. Because traffic counts only provide the portion of the demand that was served, the actual demand can be difficult to identify.

Demand relates to the number of vehicles that would like to be served by a roadway element, while volume relates to the number that are actually served.

The following sections discuss monthly, daily, and hourly variations in traffic demand. Analysts need to account for these types of variations to ensure that the peak-hour demand volumes used in an HCM analysis reflect conditions on peak days of the year. Failure to account for these variations can result in an analysis that reflects peak conditions on the days counts were made, but not peak conditions over the course of the year. For example, a highway serving a beach resort area may be virtually unused during much of the year but become oversaturated during the peak summer periods.

Seasonal peaks in traffic demand must also be considered, particularly on recreational facilities.

A roadway's capacity may be greater than its hourly demand, yet traffic flow may still break down if the flow rate within a portion of the hour exceeds the roadway's capacity. The effects of a breakdown can extend far beyond the time during which demand exceeded capacity and may take several hours to dissipate. Subhourly variations in demand and their effects on traffic flow are discussed in Chapter 4, Traffic Operations and Capacity Concepts.

A highway that is barely able to handle a peak-hour demand may be subject to breakdown if flow rates within a portion of the peak hour exceed capacity—a topic of Chapter 4.

The data shown in the exhibits in this section represent typical observations that can be made. However, the patterns illustrated vary in response to local travel habits and environments, and these examples should not be used as a substitute for locally obtained data.

Data shown in these graphs represent typical observations but should not be used as a substitute for local data.

Seasonal and Monthly Variations

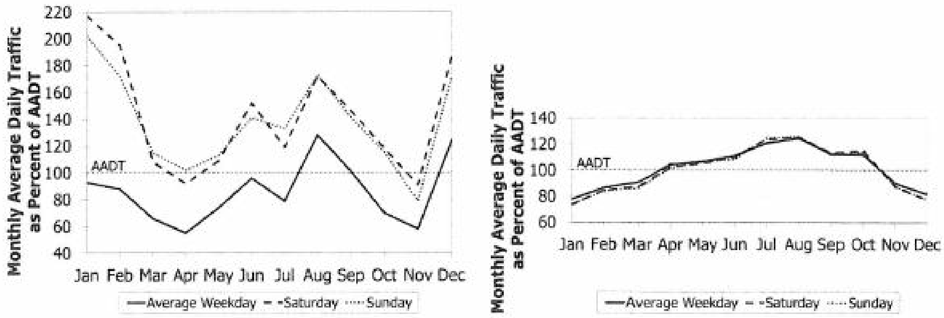
Seasonal fluctuations in traffic demand reflect the social and economic activity of the area served by the highway. Exhibit 3-2 shows monthly patterns observed in Oregon and Washington. The highway depicted in Exhibit 3-2(a) serves national forestland with both winter and summer recreational activity. The highway depicted in Exhibit 3-2(b) is a rural route serving intercity traffic. Two significant characteristics are apparent from this data set:

- The range of variation in traffic demand over the course of a year is more severe on rural routes primarily serving recreational traffic than on rural routes primarily serving intercity traffic.
- Traffic patterns vary more severely by month on recreational routes.

Exhibit 3-2
Examples of Monthly Traffic Volume Variations for a Highway

Monthly volume variations for routes with recreational traffic show much higher seasonal peaking than for routes with predominantly intercity traffic.

The average daily traffic averaged over a full year is referred to as the annual average daily traffic, or AADT, and is often used in forecasting and planning.



(a) Routes with Significant Recreational Traffic (b) Routes with Significant Intercity Traffic

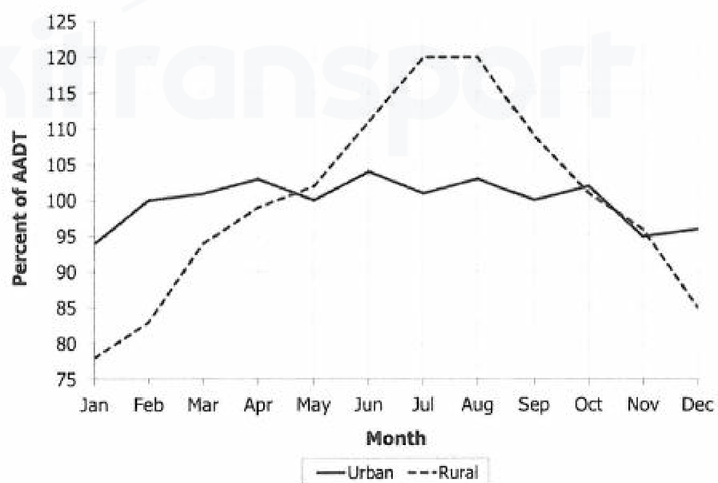
Source: (a) Oregon DOT, 2007; (b) Washington State DOT, 2007.
Notes: (a) Highway 35 south of Parkdale, Oregon; (b) US-97 north of Wenatchee, Washington.

These and similar observations lead to the conclusion that commuter- and business-oriented travel occurs in fairly uniform patterns, while recreational traffic creates the greatest variation in demand patterns.

The data for Exhibit 3-3 were collected on the same Interstate route. One segment is within 1 mi of the central business district of a large metropolitan area. The other segment is within 75 mi of the first but serves a combination of recreational and intercity travel. This exhibit illustrates that monthly variations in volume are more severe on rural routes than on urban routes. The wide variation in seasonal patterns for the two segments underscores the effect of trip purpose and may reflect capacity restrictions on the urban section.

Exhibit 3-3
Examples of Monthly Traffic Volume Variations for the Same Interstate Highway (Rural and Urban Segments)

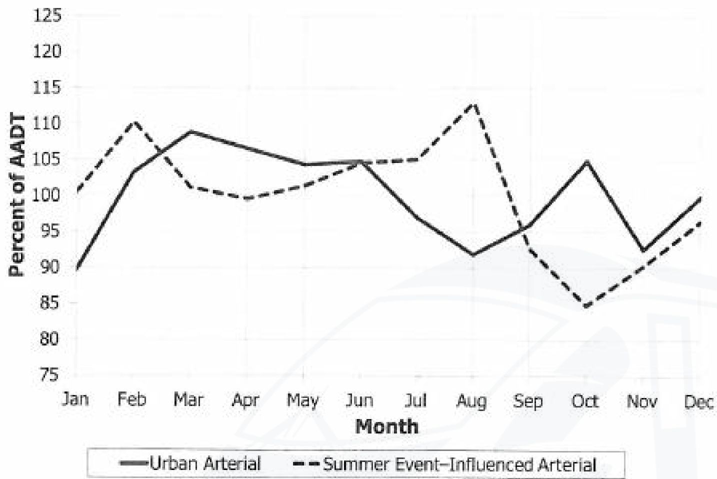
Monthly volume variations for rural segments of Interstate highways show much higher seasonal peaking than for urban segments of the same highway. This may reflect both recreational and agricultural traffic impacts.



Source: Oregon DOT, 2006.
Note: Urban, I-84 east of I-5 in Portland; rural, I-84 at Rowena.

Exhibit 3-4 shows examples of monthly traffic volume variations on two urban streets in the same large city. Comparison of these variations with those of Exhibit 3-2 and Exhibit 3-3 indicates that urban streets tend to show more month-to-month variation than urban freeways, but less variation than rural roadways. Traffic on typical urban arterials tends to drop during summer months when school is not in session, but special event (e.g., summer festival) traffic can result in higher-than-average traffic volumes during the summer.

Exhibit 3-4
Examples of Monthly Traffic Volume Variations on Urban Streets



Source: City of Milwaukee, Wisconsin, 2014.
Note: Monthly values are weekly average counts for 1 week of each month.

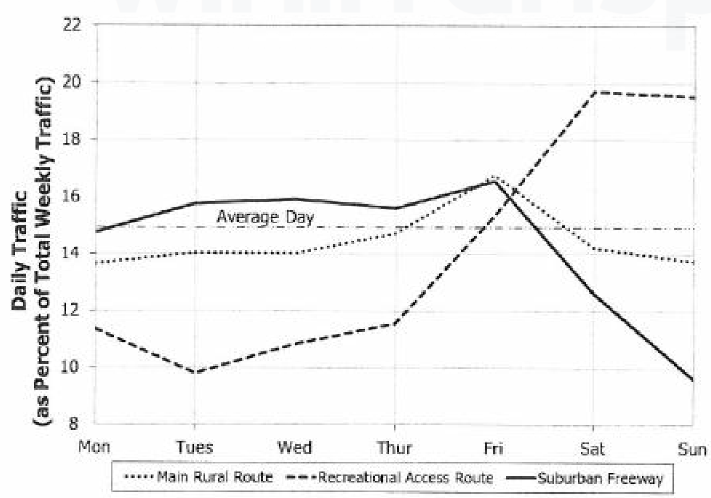
Daily Variations

Time of peak demand will vary according to highway type.

Demand variations by day of the week are also related to the type of highway. Exhibit 3-5 shows that weekend volumes are lower than weekday volumes for highways serving predominantly business travel, such as urban freeways. In comparison, peak traffic typically occurs on weekends on main rural and recreational highways. Furthermore, the magnitude of daily variation is highest for recreational access routes and lowest for urban commuter routes.

Exhibit 3-5
Examples of Daily Traffic Variation by Type of Route

Daily volume variations through the week show higher weekday volumes and lower weekend volumes for routes primarily serving commuter and intercity traffic, but the opposite for segments serving recreational traffic. Fridays are typically the peak weekday.

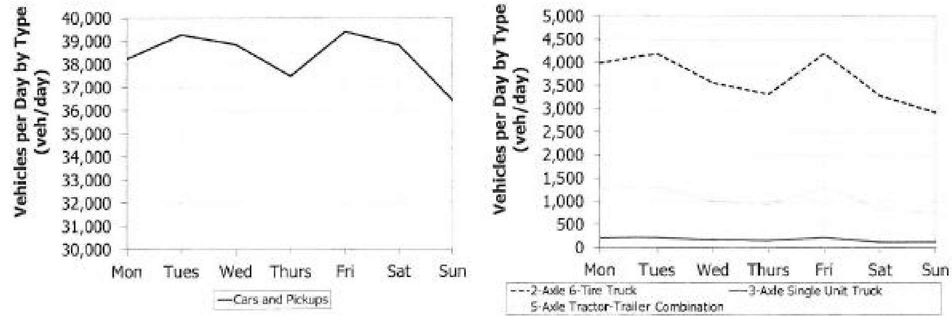


Source: Washington State DOT, 2007; Oregon DOT, 2007.
Notes: Suburban freeway, I-182 in Richland, Washington; main rural route, US-12 southeast of Pasco, Washington; recreational access route, Highway 35 south of Parkdale, Oregon.

Exhibit 3-6 shows the variation in traffic by vehicle type for the right lane of an urban freeway. Although the values shown in Exhibit 3-5 and Exhibit 3-6 are typical of patterns that may be observed, they should not be used as a substitute for local studies and analyses.

Exhibit 3-6
Daily Variation in Traffic by Vehicle Type for the Right Lane of an Urban Freeway

Daily volume variations by vehicle type through the week show higher weekday volumes and lower weekend volumes for truck traffic, with much sharper drops on the weekend for heavy truck traffic then for single-unit trucks. Car and pickup traffic peaks on Fridays and declines on weekends on this urban freeway.



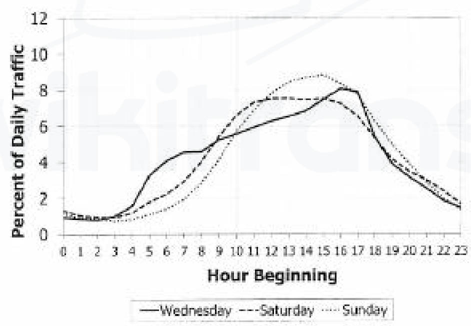
Source: Washington State DOT, 2007.
Note: Northbound Highway 16 north of I-5, Tacoma, Washington.

Hourly Variations

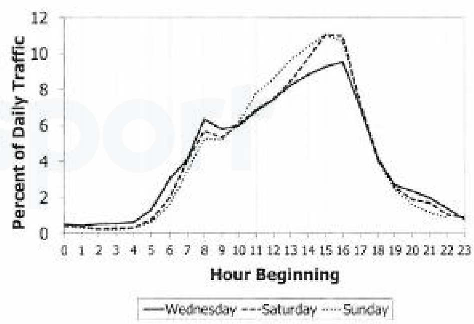
Typical hourly variation patterns for rural routes are shown in Exhibit 3-7, where the patterns are related to highway type and day of the week. Unlike urban routes, rural routes tend to have a single peak that occurs in the afternoon. A small morning peak is visible on weekdays that is much lower than the afternoon peak. The proportion of daily traffic occurring in the peak hour is much higher for recreational access routes than for intercity or local rural routes. The weekend pattern for recreational routes is similar to the weekday pattern, as travelers tend to go to their recreation destination in the morning and return in the later afternoon. Weekend morning travel is considerably lower than weekday morning travel for the other types of rural routes.

Exhibit 3-7
Examples of Hourly Traffic Variations for Rural Routes

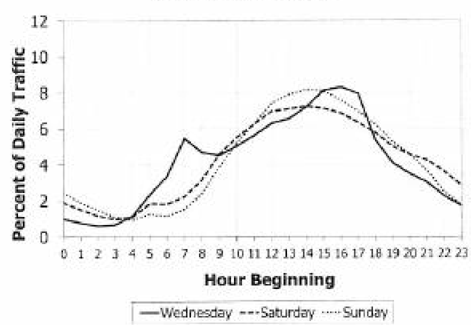
Bidirectional traffic variation during the day by day of week for rural routes.



(a) Intercity Route



(b) Recreational Access Route

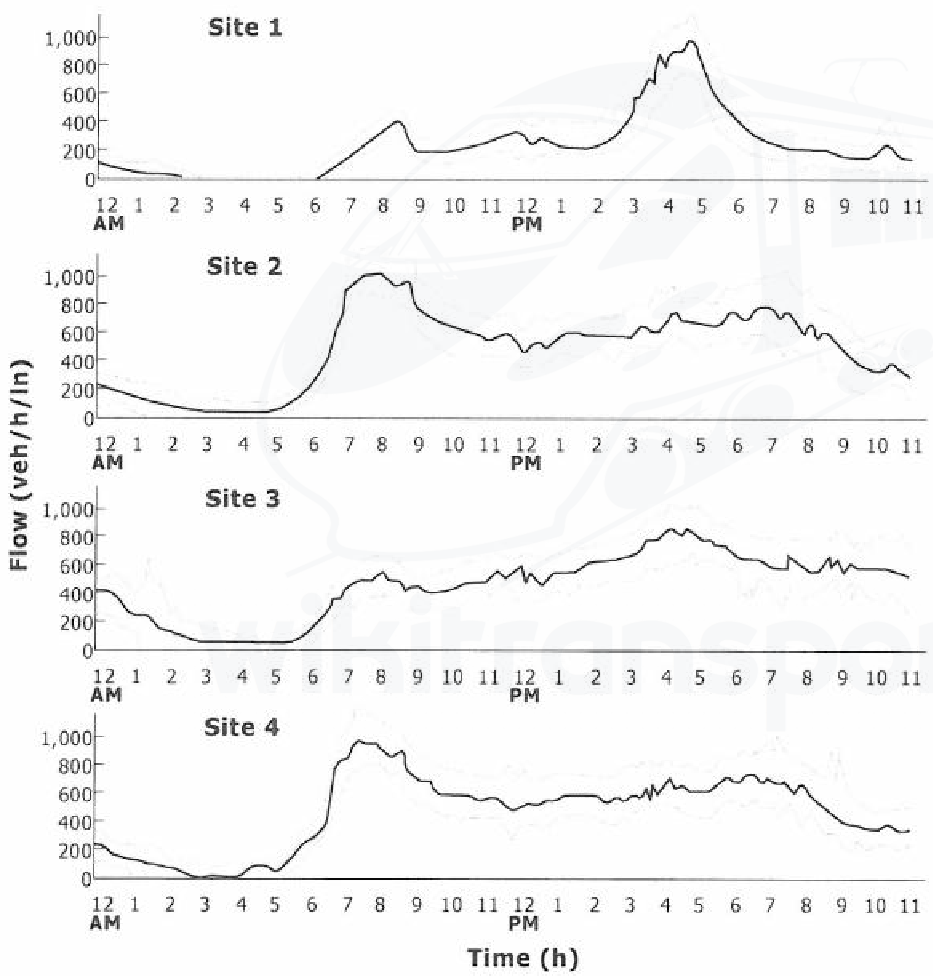


(c) Local Route

Sources: Washington State DOT, 2007; Oregon DOT, 2007.
Notes: (a) US-395 south of Kennewick, Washington; (b) Highway 35 south of Parkdale, Oregon; (c) US-97 near Wapato, Washington.

The repeatability of hourly variations is of great importance. The stability of peak-hour demand affects the feasibility of using such values in design and operational analyses of highways and other transportation facilities. Exhibit 3-8 shows data obtained for single directions of urban streets in the Toronto, Canada, region. The data were obtained from detectors measuring traffic in one direction only, as evidenced by the single peak period shown for either morning or afternoon. The area between the dotted lines indicates the range within which 95% of the observations can be expected to fall. Whereas the variations by hour of the day are typical for urban areas, the relatively narrow and parallel fluctuations among the days of the study indicate the repeatability of the basic pattern.

Exhibit 3-8
Repeatability of Hourly Traffic Variations for Urban Streets



Source: McShane and Crowley (7).
Notes: Sites 2 and 4 are one block apart on the same street, in the same direction. All sites are two moving lanes in one direction. Dotted lines indicate the range in which 95% of the observed volumes fall.

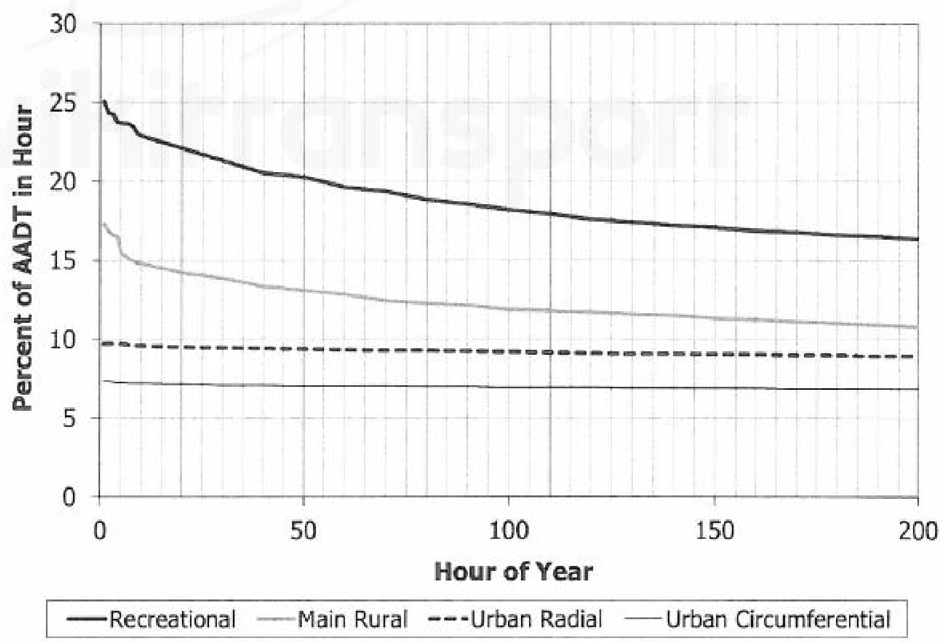
Peak Hour and Analysis Hour

Capacity and other traffic analyses typically focus on the peak-hour traffic volume because it represents the most critical period for operations and has the highest capacity requirements. However, as shown in the previous sections, the peak-hour volume is not a constant value from day to day or from season to season. If the highest hourly volumes for a given location were listed in descending order, the data would vary greatly, depending on the type of facility.

Rural and recreational routes often show a wide variation in peak-hour volumes. Several extremely high volumes occur on a few select weekends or in other peak periods, and traffic during the rest of the year flows at much lower volumes, even during the peak hour. Urban streets, on the other hand, show less variation in peak-hour traffic. Most users are daily commuters or frequent users, and occasional and special event traffic is minimal. Furthermore, many urban routes are filled to capacity during each peak hour, and variation is therefore severely constrained—an issue that will be revisited later in this section.

Exhibit 3-9 shows hourly volume relationships measured on four highway types in Washington. The recreational highway shows the widest variation in peak-hour traffic. Its values range from 25% of AADT in the highest hour of the year to about 16.3% of AADT in the 200th-highest hour of the year. The main rural freeway also varies widely, with 17.3% of the AADT in the highest hour, decreasing to 10.8% in the 200th-highest hour. The urban freeways show far less variation. The range in percent of AADT covers a narrow band, from approximately 9.7% (radial freeway) and 7.3% (circumferential freeway) for the highest hour to 8.9% and 6.9%, respectively, for the 200th-highest hour. Exhibit 3-9 is based on all hours of the year, not just peak hours of each day, and shows only the highest 200 hours of the year.

Exhibit 3-9
Ranked Hourly Volumes



Source: Washington State DOT, 2006.
Notes: Recreational, US-2 near Stevens Pass (AADT = 3,862); main rural, I-90 near Moses Lake (AADT = 10,533); urban radial, I-90 in Seattle (AADT = 120,173); urban circumferential, I-405 in Bellevue (AADT = 141,550).

The selection of an appropriate hour for planning, design, and operational purposes is a compromise between providing adequate operations for every (or almost every) hour of the year and providing economic efficiency. Customary practice in the United States is to base rural highway design on the 30th-highest hour of the year. There are few hours with higher volumes than this hour, while there are many hours with volumes not much lower. In urban areas, there is usually little difference between the 30th- and 200th-highest hours of the year, because of the recurring morning and afternoon commute patterns (*8*).

Selection of an analysis hour usually implies that a small portion of the demand during a year will not be adequately served.

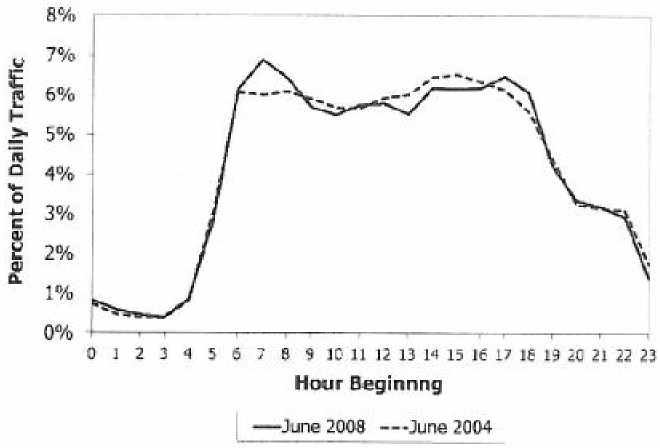
The selection of the analysis hour should consider the impact on the design and operations of higher-volume hours that are not accommodated. The recreational access route curve of Exhibit 3-9 shows that the highest hours of the year have one-third more volume than the 100th-highest hour, whereas the highest hours of an urban radial route were only about 6% higher than the volume in the 100th-highest hour. Use of a design criterion set at the 100th-highest hour would create substantial congestion on a recreational access route during the highest-volume hours but would have less effect on an urban facility. Another consideration is the LOS objective. A route designed to operate at LOS C can absorb larger amounts of additional traffic than a route designed to operate at LOS D or E during the hours of the year with higher volumes than the design hour. As a general guide, the most frequently occurring peak volumes may be considered in the design of new or upgraded facilities. The LOS during higher-volume periods should be tested to determine the acceptability of the resulting traffic conditions.

Additional analysis periods may be warranted to obtain a more robust picture of operations.

On roadways where oversaturation occurs during peak periods, analysts should be particularly careful in selecting a design hour, since measured traffic volumes may not reflect the changes in demand that occur once a bottleneck is removed. Exhibit 3-10 shows hourly variations in traffic on an urban freeway before and after the freeway was widened. In the before condition, the freeway's observed volumes were constrained by a bottleneck between 6 and 10 a.m., as indicated by the flat volume line. After the freeway widening, a more typical a.m. peak occurred, since travel patterns more closely reflected when travelers desired to travel rather than when the freeway could accommodate their travel.

Measured traffic volume patterns may not reflect actual demand patterns.

Exhibit 3-10
Example of a Change in Travel Patterns Following Removal of a Capacity Constraint



Source: Colorado DOT.
Note: I-25 south of US-6, Denver.

As used in the HCM, the *K*-factor is the proportion of AADT that occurs during the peak hour. For many rural and urban highways, this factor falls between 0.09 and 0.10. For highway sections with high peak periods and relatively low off-peak flows, the *K*-factor may exceed 0.10. Conversely, for highways that demonstrate consistent and heavy flows for many hours of the day, the *K*-factor is likely to be lower than 0.09. In general,

- The *K*-factor decreases as the AADT on a highway increases;
- The *K*-factor decreases as development density increases; and
- The highest *K*-factors occur on recreational facilities, followed by rural, suburban, and urban facilities, in descending order.

The *K*-factor should be determined, if possible, from local data for similar facilities with similar demand characteristics.

Exhibit 3-11 demonstrates how *K*-factors decrease as AADT increases, on the basis of average data from Washington State.

Exhibit 3-11
Example *K*-Factors by AADT

AADT	Average *K*-Factor	Number of Sites Included in Average *K*-Factor		
		Urban	Recreational	Other Rural
0–2,500	0.151	0	6	12
2,500–5,000	0.136	1	6	8
5,000–10,000	0.118	2	2	14
10,000–20,000	0.116	1	2	15
20,000–50,000	0.107	11	5	10
50,000–100,000	0.091	14	0	4
100,000–200,000	0.082	11	0	0
>200,000	0.067	2	0	0

Source: Washington State DOT (*9*).
Note: *K*-factors are for the 30th-highest traffic volume hour of the year.

Spatial Distributions

Traffic volume varies in space as well as time. The two critical spatial characteristics used in analyzing capacity are directional distribution and volume distribution by lane. Volume may also vary longitudinally along various segments of a facility. HCM methods incorporate this variation by breaking facilities into new segments at points where demand changes significantly; the operation of each segment is analyzed separately.

D-*Factor*

Concept of D*-factor or directional distribution.*

The *D*-factor is the proportion of traffic moving in the peak direction of travel on a given roadway during the peak hours. A radial route serving strong directional demands into a city in the morning and out at night may display a 2:1 imbalance in directional flows. Recreational and rural routes may also be subject to significant directional imbalances, which must be considered in analyses. Circumferential routes and routes connecting two major cities within a metropolitan area may have balanced flows during peak hours. Exhibit 3-12 provides examples of directional distributions from selected California freeways.

Exhibit 3-12
Example Directional Distribution Characteristics

Freeway Type	*D*-Factor
Rural–intercity	0.59
Rural–recreational and intercity	0.64
Suburban circumferential	0.52
Suburban radial	0.60
Urban radial	0.70
Intraurban	0.51

Source: California Department of Transportation, 2007.
Notes: Rural–intercity, I-5 at Willows; rural–recreational and intercity, I-80 west of Donner Summit; suburban circumferential, I-680 in Danville; suburban radial, I-80 in Pinole; urban radial, Highway 94 at I-5, San Diego; intraurban, I-880 in Hayward.

Directional distribution is an important factor in highway capacity analysis. This is particularly true for two-lane rural highways. Capacity and LOS vary substantially with directional distribution because of the interactive nature of directional flows on such facilities—the flow in one direction of travel influences flow in the other direction by affecting the number of passing opportunities. Procedures for two-lane highway analyses include explicit consideration of directional distribution.

While the consideration of directional distribution is not mandated in the analysis of multilane facilities, the distribution has a dramatic effect on both design and LOS. As indicated in Exhibit 3-12, up to two-thirds of the peak-hour traffic on urban radial routes has been observed as moving in one direction. Unfortunately, this peak occurs in one direction in the morning and in the opposite direction in the evening. Thus, both directions of the facility must have adequate capacity for the peak directional flow. This characteristic has led to the use of reversible lanes on some urban streets and highways.

Directional distribution is not a static characteristic. It changes annually, hourly, daily, and seasonally. Development in the vicinity of highway facilities often changes the directional distribution.

The *D*-factor is used with the *K*-factor to estimate the peak-hour traffic volume in the peak direction, as shown by Equation 3-1:

$$DDHV = AADT \times K \times D$$

Equation 3-1

where

$DDHV$ = directional design-hour volume (veh/h),

$AADT$ = annual average daily traffic (veh/day),

K = proportion of $AADT$ occurring in the peak hour (decimal), and

D = proportion of peak-hour traffic in the peak direction (decimal).

Lane Distribution

Concept of lane distribution.

When two or more lanes are available for traffic in a single direction, the lane use distribution varies widely. The volume distribution by lane depends on factors such as traffic regulations, traffic composition, speed and volume, the number and location of access points, the origin–destination patterns of drivers, the development environment, and local driver habits.

Because of these factors, there are no typical lane distributions. Data indicate that the peak lane on a six-lane freeway, for example, may be the shoulder, middle, or median lane, depending on local conditions.

Exhibit 3-13 gives daily lane distribution data for various vehicle types on three selected freeways. These data are illustrative and are not intended to represent typical values.

Exhibit 3-13
Lane Distribution by Vehicle Type

Highway	Vehicle Type	Percent Distribution By Lane[a] Lane 3	Lane 2	Lane 1
Lodge Freeway, Detroit	Light[b]	32.4	38.4	29.2
	Single-unit trucks	7.7	61.5	30.8
	Combinations	8.6	2.9	88.5
	All vehicles	31.3	37.8	30.9
I-95, Connecticut Turnpike	Light[b]	24.5	40.9	34.6
	All vehicles	22.5	40.4	37.1
I-4, Orlando, Florida	All vehicles	38.4	31.7	29.9

Sources: Huber and Tracy (*10*); Florida DOT, 1993.
Notes: [a] Lane 1 = shoulder lane; lanes numbered from right to left.
[b] Passenger cars, panel trucks, and pickup trucks.

The trend indicated in Exhibit 3-13 is reasonably consistent throughout North America. Heavier vehicles tend to use the right-hand lanes, partially because they operate at lower speeds than other vehicles and partially because regulations may prohibit them from using the leftmost lanes.

Lane distribution must also be considered at intersections and interchanges. It affects how efficiently the demand for a particular movement can be served, as well as lane-by-lane queue lengths. Uneven lane distributions can be a result of upstream or downstream changes in the number of lanes available and the pre-positioning of traffic for downstream turning movements.

MOTORIZED VEHICLE FACILITY TYPES

Exhibit 3-14 illustrates the kinds of motorized vehicle facilities addressed in the HCM. They are divided into two main categories: *uninterrupted-flow facilities*, where traffic has no fixed causes of delay or interruption beyond the traffic stream, and *interrupted-flow facilities*, where traffic controls such as traffic signals and STOP signs introduce delay into the traffic stream.

Exhibit 3-14
Motorized Vehicle Facility Types

(a) Freeway

(b) Multilane Highway

(c) Two-Lane Highway

(d) Urban Street

Uninterrupted Flow

Freeways are fully access-controlled, divided highways with a minimum of two lanes (and frequently more) in each direction. Certain lanes on freeways may be reserved for designated types of vehicles, such as high-occupancy vehicles or trucks. Some freeway facilities charge tolls, and their toll-collection facilities can create interrupted-flow conditions, such as on facilities where tolls are paid manually at toll plazas located on the freeway mainline. *Ramps* provide access to, from, and between freeways; some ramps have meters that control the flow of traffic onto a freeway segment.

Multilane highways are higher-speed roadways with a minimum of two lanes in each direction. They have zero or partial control of access. Traffic signals or roundabouts may create periodic interruptions to flow along an otherwise uninterrupted facility, but such interruptions are spaced at least 2 mi apart.

Two-lane highways generally have a two-lane cross section, although passing and climbing lanes may be provided periodically. Within the two-lane sections, passing maneuvers must be made in the opposing lane. Traffic signals, STOP-controlled intersections, or roundabouts may occasionally interrupt flow, but at intervals longer than 2 mi.

Interrupted Flow

Urban streets are streets with relatively high densities of driveway and cross-street access, located within urban areas. The traffic flow of urban streets is interrupted (i.e., traffic signals, all-way stops, or roundabouts) at intervals of 2 mi or less. HCM procedures are applicable to arterial and collector urban streets, including those in downtown areas.

EFFECTS OF OTHER MODES

Each mode that uses a roadway interacts with the other modal users of that roadway. This section examines the operational effects of other modes on automobiles; the effects of automobiles on other modes are discussed later in the portions of the chapter addressing those modes. In addition to the specific interactions discussed below, changes in the amount of roadway space allocated to particular travel modes and changes in the volume of users of a given mode will affect the operations and quality of service of all the modes using the roadway, with different modes being affected in different ways.

Pedestrians

Pedestrians interact with automobiles on interrupted-flow elements of the roadway system. At signalized intersections, the minimum green time provided for an intersection approach is influenced by the need to provide adequate time for pedestrians using the parallel crosswalk to cross the roadway safely. In turn, the green time allocated to a particular vehicular movement affects the capacity of and the delay experienced by that movement. At signalized and unsignalized intersections, turning vehicles must yield to pedestrians in crosswalks, which reduces the capacity of and increases the delay experienced by those turning movements, compared with a situation in which pedestrians are not present. The increased delays at intersections and midblock pedestrian crossings along urban streets that result from higher pedestrian crossing volumes lower vehicular speeds along the urban street.

Bicycles

At intersections, motorized vehicle capacity and delay are affected by bicycle volumes, particularly where turning vehicles conflict with through bicycle movements. However, HCM methodologies only account for these effects at signalized intersections. Bicycles may also delay motorized vehicles on two-lane roadways in cases where bicycles use the travel lane, causing vehicles to wait for a safe opportunity to pass. This kind of delay is not accounted for in the HCM two-lane roadway methodology, which only addresses delays associated with waiting to pass other motorized vehicles.

Trucks and Transit

Trucks and transit vehicles are longer than passenger cars and have different performance characteristics; thus, they are treated as heavy vehicles for all types of roadway elements. At intersections, buses or streetcars that stop in the vehicular travel lane to serve passengers delay other vehicles in the lane and reduce the lane's capacity; however, this effect is only incorporated into the signalized intersection methodology. Special transit phases or bus signal priority measures at signalized intersections affect the allocation of green time to the various traffic movements, with accompanying effects on vehicular capacity and delay. To accommodate truck and bus turning radii at intersections, stop bars may need to be set back from the intersection. This in turn affects the time required for vehicles on those approaches to pass through the intersection and thus the traffic signal's change and clearance intervals, all of which affect approach and intersection capacity.

3. TRUCK MODE

OVERVIEW

Trucks with a gross vehicle weight rating (GVWR) in excess of 10,000 lb account for approximately 3% of vehicles in use on highways in the United States and accumulate about 7% of all vehicle miles traveled. They are involved in 8% of all fatal crashes and 3% of all crashes (*11*).

This chapter describes the characteristics of trucks that set them apart from other motorized vehicles. Much of the material in this chapter was developed by a National Cooperative Freight Research Program project (*1*).

TRUCK CHARACTERISTICS

The HCM defines trucks as a subclass of heavy vehicles, with heavy vehicles being defined as any vehicle with more than four tires touching the ground, regardless of the number of axles. The other two subclasses of heavy vehicles within the HCM analysis framework are buses and recreational vehicles, primarily people-hauling vehicles. Trucks are the subclass of HCM heavy vehicles dedicated primarily to moving goods, equipment, or waste. Heavy vehicles mainly involved in construction or maintenance are also defined as trucks.

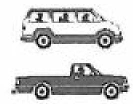
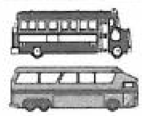
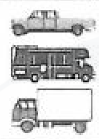
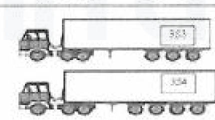
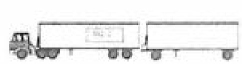
The Federal Highway Administration (FHWA) classifies all larger vehicles by the number of axles. FHWA divides two-axle vehicles into motorcycles, passenger cars, buses, and single-unit trucks, with single-unit trucks being further split into four-tire and six-tire (dual rear wheel) vehicles (see Exhibit 3-15). HCM trucks fall into FHWA Vehicle Classes 5–13. HCM buses fall into FHWA Class 4. HCM passenger cars fall into FHWA Classes 1–3.

The lengths, acceleration characteristics, and deceleration (braking) characteristics of trucks are different from those of passenger cars, which affects the amount of road capacity used by trucks. Length affects the amount of road space occupied by the truck in comparison with a passenger car. Acceleration and deceleration characteristics affect trucks' safe vehicle following distances on level, uphill, and downhill grades. They also affect trucks' maximum safe downhill speed and maximum sustainable uphill speed (*crawl speed*) on extended upgrades.

Exhibit 3-16 shows a selection of representative truck characteristics by FHWA vehicle class, derived from freeway weigh-in-motion data from Florida. Exhibit 3-17 shows how truck types are distributed by vehicle class for urban and rural freeways and multilane highways in Florida. Variations in truck percentages among facility and area types can be substantial. The percentages can also vary by time of day (*14*), although that is not shown in the exhibit.

Exhibit 3-18 shows the distribution of trucks on California freeways according to their weight-to-power ratio. A truck's acceleration capabilities are tied to this ratio, as indicated in Exhibit 3-19. Generally, the higher the weight-to-power ratio, the lower the maximum acceleration rate and the lower the crawl speed.

Exhibit 3-15
FHWA Vehicle Classification Scheme

Class	Illustration	Description
1		***Motorcycles.*** All two- or three-wheeled motorized vehicles.
2		***Passenger Cars.*** All sedans, coupes, and station wagons manufactured primarily for carrying passengers and including passenger cars pulling recreational or other light trailers.
3		***Other Two-Axle, Four-Tire Single-Unit Vehicles.*** All two-axle, four-tire vehicles, other than passenger cars. Generally pickup trucks, sport-utility vehicles, and vans.
4		***Buses.*** All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. Excludes modified buses no longer capable of mass passenger transport.
5		***Two-Axle, Six-Tire Single-Unit Trucks.*** All vehicles on a single frame with two axles and dual rear wheels. Includes some trucks, camping and recreational vehicles, and motor homes.
6		***Three-Axle Single-Unit Trucks.*** All vehicles on a single frame with three axles. Includes some trucks, camping and recreational vehicles, and motor homes.
7		***Four or More Axle Single-Unit Trucks.*** All trucks on a single frame with four or more axles.
8		***Four or Fewer Axle Single-Trailer Trucks.*** All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.
9		***Five-Axle Single-Trailer* Trucks.** All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.
10		***Six or More Axle Single-Trailer Trucks.*** All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.
11		***Five or Fewer Axle Multitrailer Trucks.*** All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.
12		***Six-Axle Multitrailer Trucks.*** All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.
13		***Seven or More Axle Multitrailer Trucks.*** All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit. Includes triple-trailer combinations.

Sources: Adapted from FHWA (*12*) and Maryland State Highway Administration (*13*).
Note: FHWA Classes 1–3 are HCM passenger cars, Class 4 is HCM buses, and Classes 5–13 are HCM trucks.

Exhibit 3-16
Characteristics of Trucks by FHWA Vehicle Class (Florida)

FHWA Vehicle Class	Average Weight (lb)	Average Length (ft)	Typical Power (hp)	Typical Weight-to-Power Ratio (lb/hp)
5	14,500	29	300	48
6	30,100	30	300	100
7	65,600	28	485	135
8	37,300	59	485	77
9	53,500	69	485	110
10	62,600	73	485	129
11	54,700	75	485	113
12	56,300	78	485	116
13	87,900	95	485	181
All	44,100	--	--	--

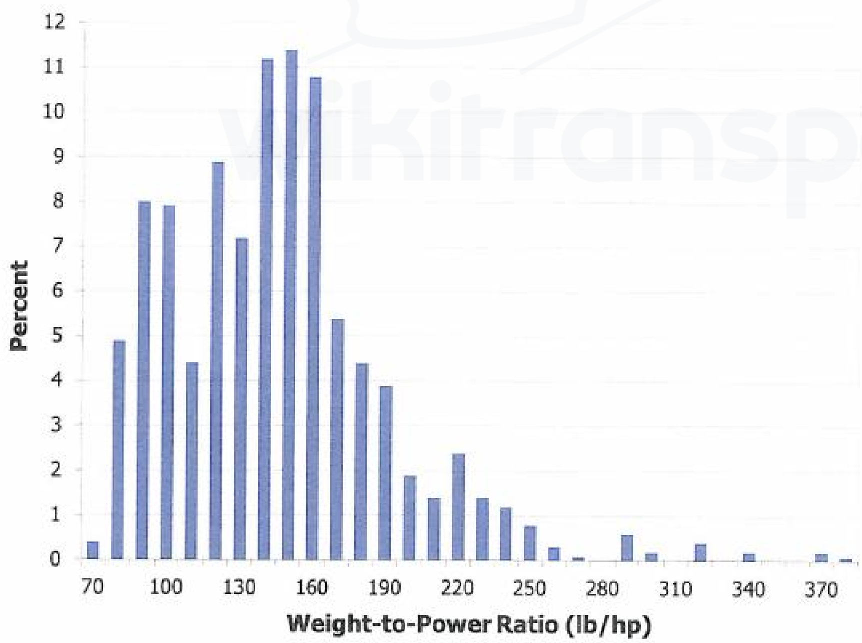
Source: Weights and lengths derived from Washburn and Ozkul (*14*) by using all-day weigh-in-motion data for 12 freeway sites in Florida for 2008–2011. Typical power from Washburn and Ozkul (*14*).
Notes: Class 4 is buses. Class 5 includes six-tire pickup trucks and recreational vehicles, along with six-tire, four-axle single-unit trucks.

Exhibit 3-17
Percentage of Trucks by FHWA Vehicle Class (Florida)

FHWA Vehicle Class	Freeways		Multilane Highways	
	Urban	Rural	Urban	Rural
5	28.6%	17.0%	33.6%	25.8%
6	6.6%	2.6%	16.7%	4.8%
7	1.3%	0.2%	3.5%	0.5%
8	11.2%	8.0%	10.3%	10.3%
9	48.3%	66.8%	34.9%	55.7%
10	0.6%	0.6%	0.5%	0.5%
11	2.1%	2.9%	0.3%	1.3%
12	0.9%	1.8%	0.2%	0.7%
13	0.3%	0.2%	0.1%	0.4%

Source: Washburn and Ozkul (*14*), based on all-day weigh-in-motion data for 24 sites in Florida for 2008–2011.
Notes: Class 5 includes six-tire pickup trucks and recreational vehicles, along with six-tire, four-axle single-unit trucks. The percentage of Class 13 in the traffic stream will depend in part on state laws permitting longer vehicles such as triple trailers. Percentages can differ significantly by time of day.

Exhibit 3-18
Weight-to-Power Ratio Distribution Example (California)



Source: Harwood et al. (*15*).
Notes: Number of observations = 1,195, 25th percentile ratio = 112, median ratio = 141, 75th percentile ratio = 164, 85th percentile ratio = 183, 95th percentile ratio = 198.
Weight-to-power distributions are available for other states in the same report.

Exhibit 3-19
Average Truck Acceleration Rate (ft/s²) to 40 mi/h

Weight-to-Power Ratio (lb/hp)	Starting Speed (mi/h) 0	10	20	30
100	1.87	1.70	1.47	1.29
200	1.22	1.08	0.96	0.79
300	0.91	0.81	0.72	0.58
400	0.71	0.61	0.50	0.36

Source: Harwood et al. (*15*).

The GVWR is the sum of the empty vehicle weight, fuel, and maximum safe load the vehicle can carry as certified by the manufacturer. For single-unit trucks (Classes 5–7), the GVWR ranges from 54,000 to 68,000 lb. For semitrailer combination trucks (Classes 8–13), the GVWR can range from 80,000 to 148,000 lb (*11*). The average weight of loaded and unloaded trucks is usually substantially less than the GVWR.

Highway load limits imposed by highway operating agencies affect which routes certain trucks can use. Operating agencies, at their discretion, also issue permits for oversize and overweight loads that allow one-time use (or multiple use) of a specified route for loads that exceed legal limits.

Trucks carrying certain hazardous materials and certain buses must come to a complete stop in the travel lane at each at-grade railroad crossing before proceeding, regardless of whether a train is present.

Unless the highway operating agency imposes different speed limits for trucks and passenger cars, trucks can usually move at the same speeds as passenger cars in level terrain. On long upgrades (4% or greater for 0.5 mi or more) or long downgrades (4% or greater downgrades extending for 0.5 mi or more), trucks will operate at lower speeds than passengers cars. This causes turbulence when the passenger cars attempt to pass the trucks and general reductions in overall speeds, especially when trucks pass each other on the grade.

EFFECTS OF OTHER MODES

This section examines the operational effects of other modes on the truck mode; the effects of the truck mode on other modes are discussed in the portions of the chapter addressing those modes.

Automobiles

A focus group of Canadian truck drivers with excellent driving records (*16*) found that truck drivers felt that automobile drivers were less consistent in their driving behavior than were truck drivers, which affected truck drivers' perceptions of safety. This study and a study of American truck drivers (*17*) also found that while truck drivers were concerned about travel times and maneuverability, their most important concern was their need to move at a steady speed, without much braking or changing of gears. As a result of these issues, nighttime was considered "premium truck traffic time," since trucks could travel without interference from automobiles during that time and thus have more reliable travel times (*16*).

Pedestrians

The pedestrian–automobile interactions described previously also affect truck operations. However, because of trucks' poorer acceleration capabilities, stops created by the need to yield to pedestrians have a more severe impact on truck operations than on automobile operations. In addition, trucks have longer braking distances, and therefore pedestrians' potentially unpredictable behavior is a greater concern for truck drivers (*16*).

Bicycles

The bicycle–automobile interactions described previously also affect truck operations.

Transit

Buses stopping in the travel lane on urban streets to serve passengers have a greater effect on trucks than on automobiles because of (*a*) the greater delay caused by trucks' poorer acceleration capabilities and, on multilane streets, (*b*) the larger gap in traffic that is required for trucks to change lanes to pass the bus.

4. PEDESTRIAN MODE

OVERVIEW

Approximately 10% of all trips in the United States are accomplished by walking (*18*). Moreover, many automobile trips and most transit trips include at least one section where the traveler is a pedestrian. When a network of safe and convenient pedestrian facilities is provided and potential destinations are located within walking distance of the trip origin, walking can be the mode of choice for a variety of shorter trips, including going to school, running errands, and recreational and exercise trips.

HUMAN FACTORS

Pedestrians are considerably more exposed than are motorists, in both good and bad ways. Pedestrians travel much more slowly than other modal users and can therefore pay more attention to their surroundings. The ability to take in surroundings and get exercise while doing so can be part of the enjoyment of the trip. At the same time, pedestrians interact closely with other modal users, including other pedestrians, with safety, comfort, travel hindrance, and other implications. In addition, pedestrians are exposed to the elements. As a result, a number of environmental and perceived safety factors significantly influence pedestrian quality of service. In locations with large numbers of pedestrians, pedestrian flow quality is also a consideration.

Some pedestrian flow measures are similar to those used for vehicular flow, such as the freedom to choose desired speeds and to bypass others. Others are related specifically to pedestrian flow, such as (*a*) the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, and to maneuver without conflicts or changes in walking speed and (*b*) the delay experienced by pedestrians at signalized and unsignalized intersections.

Environmental factors contribute to the walking experience and, therefore, to the quality of service perceived by pedestrians. These factors include the comfort, convenience, safety, and security of the walkway system. Comfort factors include weather protection; proximity, volume, and speed of motor vehicle traffic; pathway surface; and pedestrian amenities. Convenience factors include walking distances, intersection delays, pathway directness, grades, sidewalk ramps, wayfinding signage and maps, and other features making pedestrian travel easy and uncomplicated.

Safety is provided by separating pedestrians from vehicular traffic both horizontally, by using pedestrian zones and other vehicle-free areas, and vertically, by using overpasses and underpasses. Traffic control devices such as pedestrian signals can provide time separation of pedestrian and vehicular traffic, which improves pedestrian safety. Security features include lighting, open lines of sight, and the degree and type of street activity.

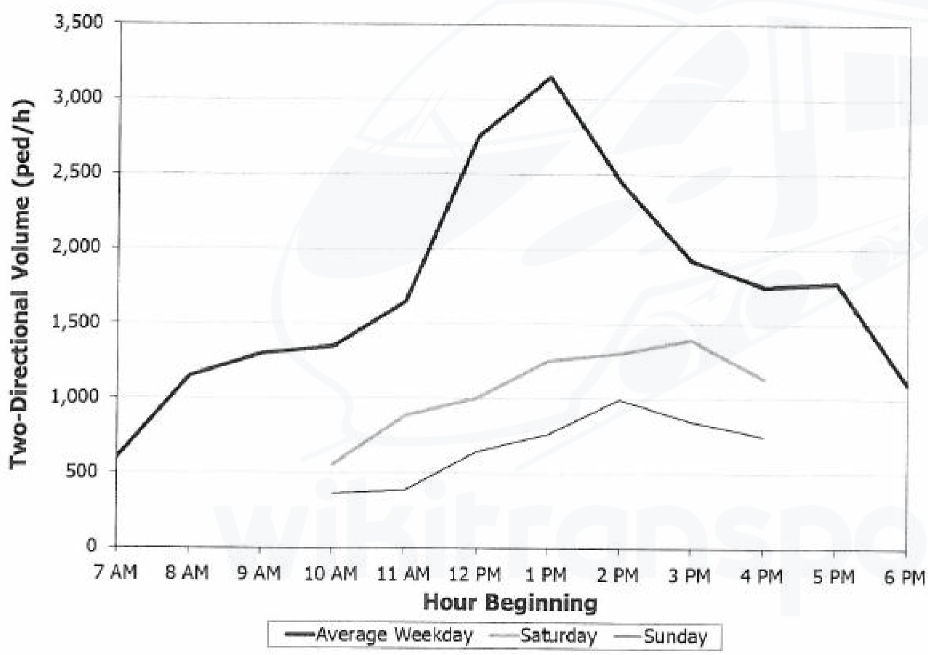
Chapter 4, Traffic Operations and Capacity Concepts, discusses pedestrian flow measures, such as speed, space, and delay, while Chapter 5, Quality and

Level-of-Service Concepts, covers the environmental factors that influence pedestrian quality of service.

VARIATIONS IN DEMAND

Pedestrian demand differs from that of the other modes addressed in the HCM in that the peak pedestrian demand often occurs at midday or during the early afternoon. Depending on the location, secondary peaks or plateaus in demand may also occur during the weekday a.m. and p.m. peak hours. Exhibit 3-20 shows two-directional pedestrian volume data collected in May 2004 on a sidewalk in Lower Manhattan, for an average of 5 weekdays in a week, Saturday, and Sunday. Although weekday demand was considerably higher than weekend demand, a single peak can be seen clearly in all three counts. Work-related trips made up the majority of a.m. peak-period pedestrian trips, while non-work-related and tourist trips made up the majority of the midday and early afternoon pedestrian trips (*19*).

Exhibit 3-20
Illustrative Temporal Variations in Pedestrian Demand

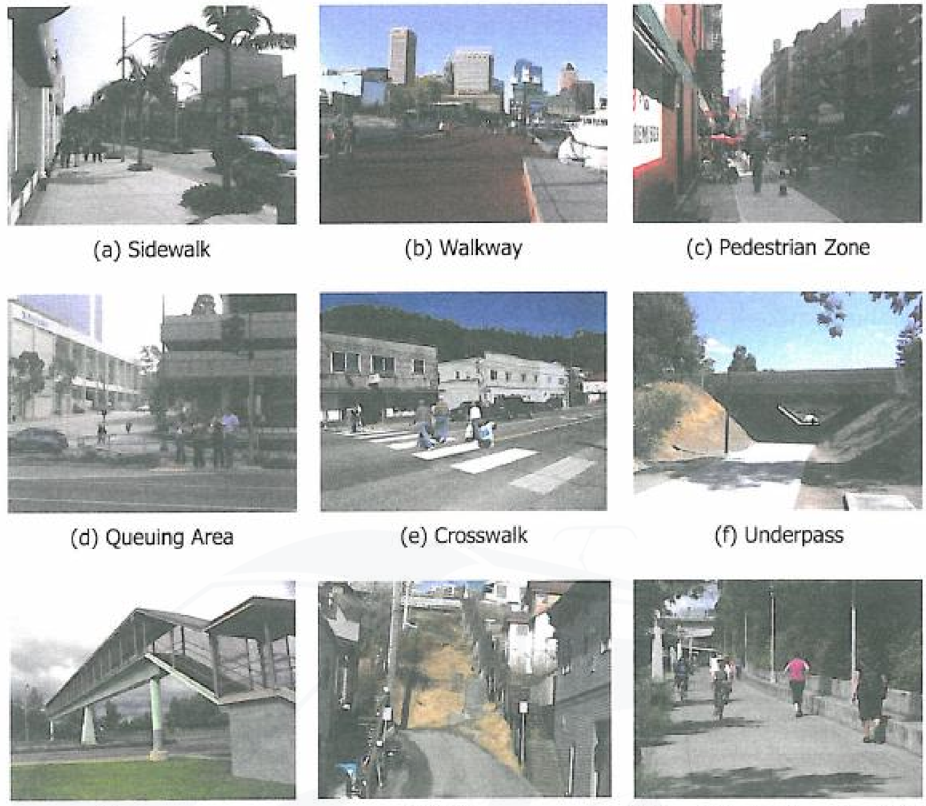


Source: Adapted from New York City Department of City Planning (*19*).

PEDESTRIAN FACILITY TYPES

Exhibit 3-21 illustrates the types of pedestrian facilities addressed in the HCM. The following sections define each type of facility.

Exhibit 3-21
Pedestrian Facility Types



(a) Sidewalk | (b) Walkway | (c) Pedestrian Zone
(d) Queuing Area | (e) Crosswalk | (f) Underpass
(g) Overpass | (h) Stairway | (i) Shared Pedestrian–Bicycle Path

Sidewalks, Walkways, and Pedestrian Zones

These three facility types are separated from motor vehicle traffic and typically are not designed for bicycles or other users, other than persons in wheelchairs. They accommodate higher volumes of pedestrians and provide better levels of service than do similarly sized shared-use paths, because pedestrians do not share the facility with other modes traveling at higher speeds.

Sidewalks are located parallel and in proximity to roadways. Pedestrian walkways are similar to sidewalks in construction and may be used to connect sidewalks, but they are located well away from the influence of automobile traffic. Pedestrian zones are streets that are dedicated to pedestrian use on a full- or part-time basis.

Pedestrian walkways are also used to connect portions of transit stations and terminals. Pedestrian expectations concerning speed and density in a transit context are different from those in a sidewalk context; the *Transit Capacity and Quality of Service Manual* (*20*) provides more information on this topic.

Queuing Areas

Queuing areas are places where pedestrians stand temporarily while waiting to be served, such as at the corner of a signalized intersection. In dense standing crowds, there is little room to move, and circulation opportunities are limited as the average space per pedestrian decreases.

Pedestrian Crosswalks

Pedestrian crosswalks, whether marked or unmarked, provide connections between pedestrian facilities across sections of roadway used by motorized vehicles, bicycles, and transit vehicles. Depending on the type of control used for the crosswalk, local laws, and driver observance of those laws, pedestrians will experience varying levels of delay, safety, and comfort while using the crosswalk.

Stairways

Stairways are sometimes used to help provide pedestrian connectivity in areas with steep hills, employing the public right-of-way that would otherwise contain a roadway. They are often also used in conjunction with a ramp or elevator to provide shorter access routes to overpasses, underpasses, or walkways located at a different elevation. Even a small number of pedestrians moving in the opposite direction of the primary flow can significantly decrease a stairway's capacity to serve the primary flow.

Overpasses and Underpasses

Overpasses and underpasses provide a grade-separated route for pedestrians to cross wide or high-speed roadways, railroad tracks, busways, and topographic features. Access is typically provided by a ramp or, occasionally, an elevator, which is often supplemented with stairs. Procedures exist for assessing the quality of pedestrian flow on these facilities, but not the quality of the pedestrian environment.

Shared Pedestrian–Bicycle Paths

Shared pedestrian paths typically are open to use by nonmotorized modes such as bicycles, skateboards, and inline skaters. Shared-use paths often are constructed to serve areas without city streets and to provide recreational opportunities for the public. They are common on university campuses, where motor vehicle traffic and parking are often restricted. In the United States, there are few paths exclusively for pedestrians; most off-street paths, therefore, are for shared use.

On shared facilities, bicycles—because of their markedly higher speeds—can negatively affect pedestrian capacity and quality of service. However, it is difficult to establish a bicycle–pedestrian equivalent because the relationship between the two depends on the characteristics of the cycling population, the modes' respective flows and directional splits, and other factors.

EFFECTS OF OTHER MODES

Automobiles and Trucks

At signalized intersections, the delay experienced by pedestrians is influenced by the amount of green time allocated to serve vehicular volumes on the street being crossed. The volume of motorized vehicles making turns across a crosswalk at an intersection also affects a pedestrian's delay and perception of the intersection's quality of service.

At unsignalized intersections, increased major-street traffic volumes affect pedestrian crossing delay by reducing the number of opportunities for pedestrians to cross. The effect of motorized vehicle volumes on pedestrian delay at unsignalized intersections also depends on local laws specifying yielding requirements to pedestrians in crosswalks and driver observation of those laws.

Automobile and heavy vehicle traffic volumes and the extent to which pedestrians are separated from vehicular traffic influence pedestrians' perceptions of quality of service while walking along a roadway.

Large intersection corner turning radii required to accommodate turning heavy vehicles increase pedestrian crossing distances, which increases pedestrian exposure, as well as the length of the pedestrian clearance interval for the affected crosswalks. The latter factor influences the approach and intersection capacity.

Bicycles

Bicycle interaction with pedestrians is greatest on pathways shared by the two modes. Bicycles—because of their markedly higher speeds—can negatively affect pedestrian capacity and quality of service on such pathways.

Transit

The interaction of transit vehicles with pedestrians is similar to that of automobiles. However, because transit vehicles are larger than automobiles, the effect of a single transit vehicle is proportionately greater than that of a single automobile. The lack of pedestrian facilities in the vicinity of transit stops can be a barrier to transit access, and transit quality of service is influenced by the quality of the pedestrian environment along streets with transit service. Although it is not addressed by the HCM procedures, the pedestrian environment along the streets used to get to and from the streets with transit service also influences transit quality of service. Passengers waiting for buses at a bus stop can reduce the effective width of a sidewalk, while passengers getting off buses may create cross flows that interact with the flow of pedestrians along a sidewalk.

5. BICYCLE MODE

OVERVIEW

Bicycles are used to make a variety of trips, including trips for recreation and exercise, commutes to work and school, and trips for errands and visiting friends. Bicycles help extend the market area of transit service, since bicyclists can travel about five times as far as an average person can walk in the same amount of time. Although bicycle trip making in North America is lower than in other parts of the world, several large North American cities that have invested in bicycle infrastructure and programs (e.g., Portland, Oregon; Minneapolis, Minnesota; Seattle, Washington; Washington, D.C.; and Vancouver, Canada) have bicycle commute mode splits between 4% and 6% (2012 census and local data). Some college towns have even higher commute mode splits, such as Eugene, Oregon (8%); Boulder, Colorado (12%); and Davis, California (19%), according to 2012 census data.

HUMAN FACTORS

Many of the measures of vehicular effectiveness can also describe bicycling conditions, whether on exclusive or shared facilities. As with motor vehicles, bicycle speeds remain relatively insensitive to flow rates over a wide range of flows. Delays due to traffic control affect bicycle speeds along a facility, and the additional effort required to accelerate from a stop is particularly noticeable to bicyclists. Grades, bicycle gearing, and the bicyclist's fitness level also affect bicycle speed and the level of effort required to maintain a particular speed.

Electric and electric assist bicycles are gaining popularity. They help address concerns such as accelerating from a stop and climbing up hills that affect human-powered bicycles.

Some vehicular measures are less applicable to the bicycle mode. For example, bicycle density is difficult to assess, particularly with regard to facilities shared with pedestrians and others. Because of the severe deterioration of service quality at flow levels well below capacity (e.g., freedom to maneuver around other bicyclists), the concept of capacity has little utility in the design and analysis of bicycle paths and other facilities. Capacity is rarely observed on bicycle facilities. Values for capacity therefore reflect sparse data, generally from European studies or from simulation.

Hindrance as a bicycle-specific performance measure.

Other measures of bicycle quality of service have no vehicular counterpart. For example, the concept of hindrance relates directly to bicyclists' comfort and convenience (*21*). During travel on a bicycle facility, bicyclists meet other pathway users in the opposite direction and overtake pathway users moving in the same direction. Each meeting or passing event can cause discomfort, delay, or both (hindrance) to the bicyclist.

As is the case with pedestrians, environmental factors contribute significantly to the bicycling experience and, therefore, to quality of service. These factors include the volume and speed of adjacent vehicles, the presence of heavy vehicles, the presence of on-street parking, the quality of the pavement, and the frequency and quality of street sweeping and snow-clearing activities. Chapter 5, Quality and Level-of-Service Concepts, discusses environmental and hindrance factors, while Chapter 4, Traffic Operations and Capacity Concepts, presents bicycle flow measures.

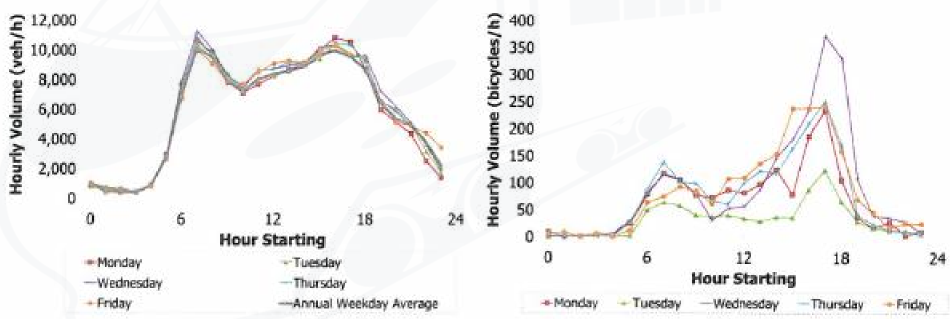
VARIATIONS IN DEMAND

Bicycle travel demand varies by time of day, day of the week, and month of the year. All of these variations are related to trip-making demands in general (e.g., bicycle commuting demand is highest during weekday a.m. and p.m. peak periods, just as with motor vehicles). However, bicyclists are more exposed than motorists to the elements and other roadway users. Dutch research shows that weather explains up to 80% of annual variation in bicycle travel, with higher rainfall and lower temperatures resulting in lower rates of bicycling (22).

The greater variability in bicycle than in automobile demand is partly due to environmental effects and partly due to the generally greater variability inherent in lower traffic volumes.

Exhibit 3-22 illustrates that bicycle demand is much more variable than is demand for motorized vehicles. The exhibit compares observed hourly bicycle volumes on a multiuse path in Minneapolis with observed hourly vehicle volumes on a parallel freeway a couple of miles away, for 1 week in October 2013. The daily freeway volumes are similar, with the p.m. peak-hour volume varying only 5% from the lowest-volume to the highest-volume day. In contrast, the bicycle volumes show 200% variability in the p.m. peak hour, a result of 1 in. of rain on Tuesday, 0.5 in. of rain on Monday and Thursday, 0.1 in. on Friday, and 0.01 in. on Wednesday. The greater variability in bicycle volumes means that longer counting periods are needed to obtain accurate bicycle demand estimates (23).

Exhibit 3-22
Illustrative Comparison of Motorized Vehicle and Bicycle Demand Variability

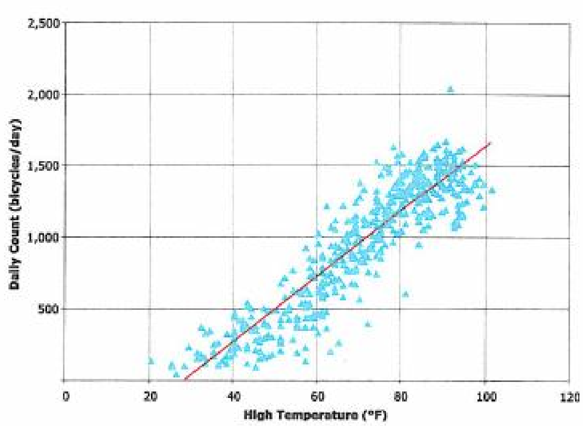


(a) Freeway (b) Multiuse Path

Source: Ryus et al. (*23*).
Note: (a) Freeway: I-394, Minneapolis. (b) Multiuse path: Midtown Greenway, Minneapolis.

Variations in bicycle demand are related to weather and daylight. For example, Exhibit 3-23 shows observations of bicycle demand compared with variations in daily high temperature along a bicycle path in Colorado.

Exhibit 3-23
Example Variations in Bicycle Demand due to Temperature

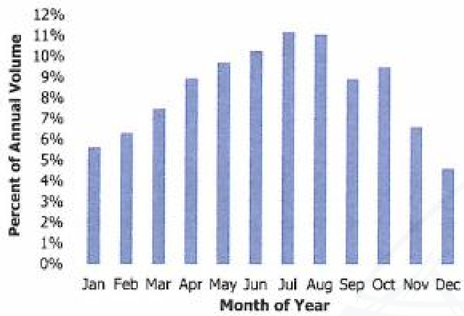


Source: Lewin (*24*).

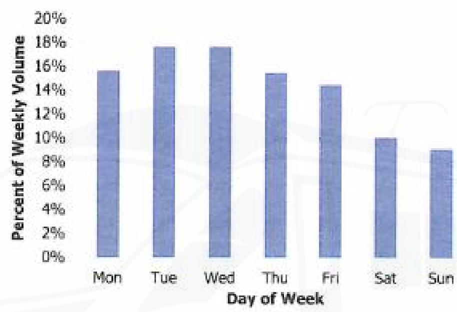
Environmental effects on bicycle demand are also apparent in Exhibit 3-24(a), which shows that the coldest and darkest months of the year have the lowest bicycle volumes. Rainfall effects can also be observed in September, when three times the normal rainfall occurred, and in October, when one-third the normal rainfall occurred. Exhibit 3-24(b) shows daily variations observed on a main bicycle commuter route. Considerable differences in volume between weekdays can be observed, and weekend demands are noticeably lower. The demand pattern observed on a recreational route would likely show higher weekend volumes relative to weekday volumes. Exhibit 3-24(c) shows hourly variations observed on the same bicycle commuter route and indicates that commuter bicycle traffic experiences a.m. and p.m. peaks.

The greater variability in bicycle volumes means that longer counting periods are needed to obtain accurate bicycle demand estimates.

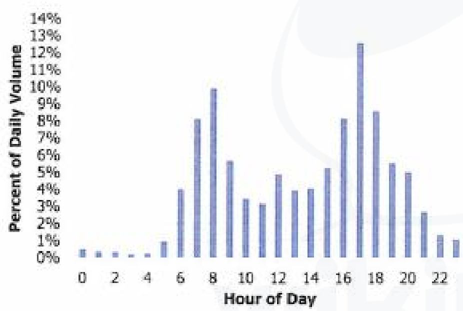
Exhibit 3-24
Illustrative Temporal Variations in Bicycle Demand



(a) Monthly Variations



(b) Daily Variations on a Commuter Route



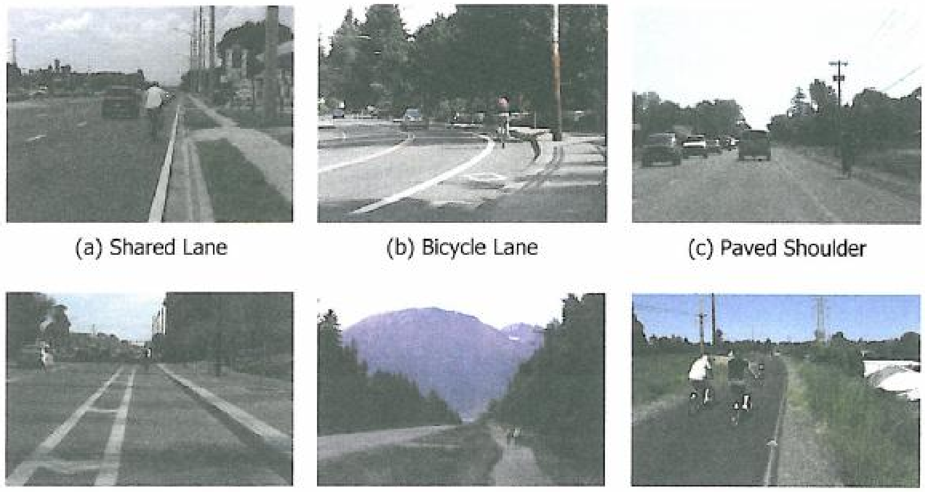
(c) Hourly Variations on a Commuter Route

Source: Portland Bureau of Transportation, Hawthorne Bridge.
Notes: (a) Data for 2013, westbound (into downtown).
(b) Data for July 8–September 8, 2013, westbound, excluding the week of August 5–11, when a bicycle event occurred that made Sunday the highest-volume day of the week.
(c) Data for 2008, including both travel directions.

BICYCLE FACILITY TYPES

Exhibit 3-25 illustrates the types of bicycle facilities addressed in the HCM. The facilities are divided into two types, on-street and off-street, and include situations in which a facility is shared with users of another mode (e.g., a lane shared by bicyclists and motor vehicle traffic or a pathway shared by bicyclists and pedestrians).

Exhibit 3-25
Bicycle Facility Types



(a) Shared Lane (b) Bicycle Lane (c) Paved Shoulder

(d) Buffered Bicycle Lane (e) Sidepath (f) Exclusive Pathway

On-Street Bicycle Facilities

On-street bicycle facilities include roadways on which bicycles share a travel lane with motorized vehicular traffic; dedicated on-street bicycle lanes; paved roadway shoulders available for use by bicyclists; and buffered bicycle lanes, where a painted island separates bicycle and motorized vehicle traffic. Bicycle flow is typically one-way, but some two-way facilities have been developed. The quality of bicycle flow, safety, and the bicycling environment are all considerations for these types of facilities.

Off-Street Bicycle Facilities

Off-street bicycle facilities consist of pathways dedicated to the exclusive use of bicyclists and pathways shared with pedestrians and other types of users. These types of facilities may be located parallel and in proximity to roadways (*sidepaths*), or they may be completely independent facilities, such as recreational trails along former railroad rights-of-way and off-street pathways of the kind found in city parks and on college campuses. Bicycle flow along these types of facilities is typically two-way and is often shared with users of other modes. The number of meeting and passing events between cyclists and other path users affects the quality of service for bicyclists using these facility types. The presence and design of driveways and intersections may affect the quality of service of bicyclists on sidepaths but is not addressed by HCM procedures.

EFFECTS OF OTHER MODES

Automobiles

Traffic volumes and speeds, the presence of on-street parking (which presents the potential for bicyclists to hit or be hit by car doors), and the degree to which bicyclists are separated from traffic all influence bicyclists' perceptions of the quality of service received during use of an on-street bicycle facility. Turning vehicles, particularly right-turning vehicles that cross the path of bicyclists, also affect quality of service.

Pedestrians

The effect of pedestrians on bicycles is greatest on pathways shared by the two modes. Pedestrians—because of their markedly lower speeds and tendency to travel in groups several abreast—can negatively affect bicycle quality of service on such pathways. Bicyclists must yield to crossing pedestrians, and the signal timing at intersections reflects, in part, the time required for pedestrians to cross the street.

Transit Vehicles and Trucks

Transit vehicles and trucks interact with bicycles in much the same way as automobiles. However, because of the greater size of these vehicles and the potential for wind blast, the effect of a single vehicle is proportionately greater than that of a single automobile. Heavy vehicle blind spots can also create safety issues when these vehicles make right turns across bicycle facilities.

Buses affect bicyclists when they pull over into a bicycle lane or paved shoulder to serve a bus stop; however, this impact is not accounted for in HCM procedures. Although not addressed by HCM procedures, the availability of good bicycle access extends the capture shed of a transit stop or station, and when bicycles can be transported by transit vehicles, transit service can greatly extend the range of a bicycle trip.

6. TRANSIT MODE

OVERVIEW

Transit plays two major roles in North America. First, it accommodates *choice* riders—those who choose transit for their mode of travel even though they have other means available. These riders choose transit to avoid congestion, save money on fuel and parking, use their travel time productively for other activities, and reduce the impact of automobile driving on the environment, among other reasons. Transit is essential for mobility in the central business districts of some major cities.

The other major role of transit is to provide basic mobility for segments of the population that are unable to drive for age, physical, mental, or financial reasons. In 2009, about 31% of Americans and Canadians did not have a driver's license (*25, 26*) and depended on others to transport them (e.g. , in automobiles, in taxis, on transit) or walked or biked. These transit users have been termed *transit-dependent* or *captive* riders.

HUMAN FACTORS

Transit passengers frequently rely on other modes to gain access to transit. Typical transit users do not have transit service available at the door and must walk, bicycle, or drive to a transit stop and walk or bicycle from the transit discharge point to their destination. Consequently, transit use is greater where population and job densities are higher and access options are good.

Unlike other modes, transit is primarily focused on a service rather than a facility.

Unlike the other modes addressed in the HCM, transit is primarily focused on a service rather than a facility. Roadways, bicycle lanes, and sidewalks, once constructed, are generally available at all times to users. Transit service, in contrast, is only available at designated times and places. Another important difference is that all transit users are passengers, rather than drivers, and not in direct control of their travel. Thus, the frequency and reliability of service are important quality-of-service factors for transit users. Travel speed and comfort while making a trip are also important to transit users.

In evaluating priority measures for transit, the number of people affected is often more relevant than the number of vehicles affected.

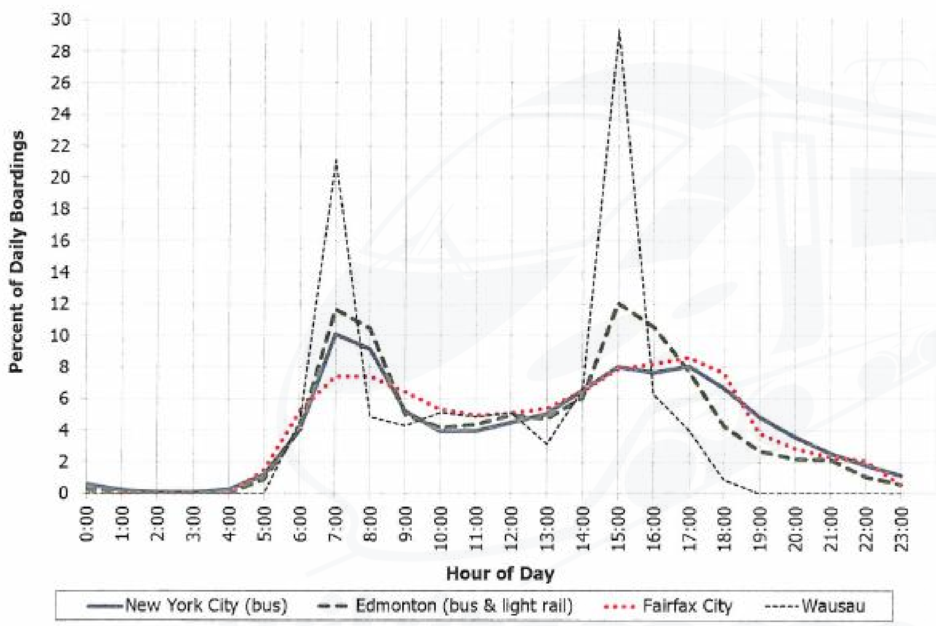
Transit is about moving people rather than vehicles. Transit operations at their most efficient level involve relatively few vehicles, each carrying a large number of passengers. In contrast, roadway capacity analysis typically involves relatively large numbers of vehicles, most carrying only a single occupant. In evaluating priority measures for transit, the number of people affected is often more relevant than the number of vehicles.

VARIATIONS IN DEMAND

Similar to other modes, transit passenger demand has distinct peaking patterns. Although these patterns typically coincide with peak commuting periods and—in many cases—school schedules, the patterns can vary substantially with the size and type of transit market being served. As an illustration, Exhibit 3-26 shows peaking patterns associated with four transit systems (*20*):

- Wausau, Wisconsin (2011 population 39,000), a relatively small community where school travel dominates transit demand patterns;
- Fairfax City, Virginia (population 25,000), a suburb of Washington, D.C., whose two-line bus system serves both commuter demands into the center of the region and student demands from the region to the university located in the city;
- Edmonton, Alberta, Canada (population 812,000), a sprawling city with bus and light rail service, a major university, and significant downtown employment; and
- New York City (population 8.2 million), a very dense city offering a variety of transportation options.

Exhibit 3-26
Illustrative Time-of-Day Variations in Transit Demand



Sources: Lu and Reddy (*27*), City of Edmonton (*28*), Connetics Transportation Group (*29*), Urbitran Associates and Abrams-Cherwony & Associates (*30*), presented in the *Transit Capacity and Quality of Service Manual* (*20*).

In all cases, an a.m. and a p.m. peak can be observed, but the sharpness of the peak differs from one location to the next. As regional population increases and the difference between peak-direction and off-peak-direction travel demand lessens, the relative size of the peak decreases. This characteristic has implications for the number of transit vehicles and drivers needed to provide service—fewer vehicles and drivers are needed solely to serve peak demand when smaller peaks exist—which, in turn, affects transit operating costs (*20*).

ON-STREET TRANSIT CHARACTERISTICS

The TCQSM comprehensively addresses transit modes.

The HCM addresses only those fixed-route transit modes that operate on roadways and interact with other roadway users. These modes are buses, streetcars, and light rail, illustrated in Exhibit 3-27 and described briefly in the following sections. The *Transit Capacity and Quality of Service Manual* (*20*) comprehensively describes transit mode characteristics.

Exhibit 3-27
Transit Modes Addressed in the HCM

(a) Bus (b) Streetcar (c) Light Rail

Bus

The bus mode is operated by rubber-tired vehicles that follow fixed routes and schedules along roadways. Although the electric trolleybus (a bus receiving its power from overhead electric wires) and bus rapid transit are classified as separate modes by the Federal Transit Administration, for HCM purposes they are treated as buses. The bus mode offers considerable operational flexibility. Service can range from local buses stopping every two to three blocks along a street, to limited-stop or bus rapid transit service stopping every ½ to 1 mi, to express service that travels along a roadway without stopping. Exhibit 3-28 provides typical acceleration characteristics of transit buses.

Exhibit 3-28
Transit Bus Acceleration Characteristics

	Average Time to Reach Speed (s)			Average Acceleration to Speed (ft/s²)	
Bus Type	**10 mi/h**	**20 mi/h**	**50 mi/h**	**20 mi/h**	**50 mi/h**
40-ft standard diesel	5.0	8.7	33.2	3.4	2.2
45-ft motor coach diesel	4.0	7.4	27.1	4.0	2.7
60-ft articulated diesel	4.0–4.7	9.1	42.3–43.6	3.2	1.7
Double deck diesel	6.2	10.4	43.6	2.8	1.7
60-ft articulated hybrid	3.8	8.6	35.2	3.4	2.1

Source: Hemily and King (*31*).

Streetcar and Light Rail

The streetcar and light rail modes are operated by vehicles that receive power from overhead electric wires and run on tracks. Streetcars tend to be shorter and narrower, to be more likely to operate in mixed traffic, and to have shorter stop spacings than light rail trains.

ON-STREET TRANSIT FACILITY TYPES

Mixed Traffic

More than 99% of the bus route miles in the United States are operated in mixed traffic. In contrast, most rail route miles—other than portions of streetcar lines—operate in some form of segregated right-of-way. In mixed traffic, transit vehicles are subject to the same causes of delay as are other motorized vehicles, and they need to stop periodically to serve passengers. These stops can cause transit vehicles to fall out of any traffic signal progression that might be provided along the street and to incur greater signal delay than other vehicles.

Exclusive Lanes

Exclusive lanes are on-street lanes dedicated for use by transit vehicles on either a full-time or a part-time basis. They are generally separated from other lanes by just a stripe, and buses may be able to leave the exclusive lane to pass buses or obstructions such as delivery trucks. Right-turning traffic, bicycles, carpools, and taxis are sometimes allowed in exclusive bus lanes. Generally, no other traffic, with the possible exception of transit buses, is allowed in exclusive lanes provided for rail transit vehicles. Exclusive lanes allow transit vehicles to bypass queues of vehicles in the general traffic lanes and reduce or eliminate delays to transit vehicles caused by right-turning traffic. Therefore, these lanes can provide faster, more reliable transit operations.

On-Street Transitways

Buses and trains sometimes operate within a portion of the street right-of-way that is physically segregated from other traffic: in the median or adjacent to one side of the street. No other traffic is allowed in the transitway. The amount of green time allocated to transit vehicles may be different from the amount of time allocated to the parallel through movements—for example, it might be reduced to provide time to serve conflicting vehicular turning movements.

EFFECTS OF OTHER MODES

Automobiles and Trucks

Higher motorized vehicle volumes result in greater delays for all traffic, including buses. In locations where buses pull out of the travel lane to serve bus stops and yield-to-bus laws are not in place (or generally observed), buses experience delay waiting for a gap to pull back into traffic after serving a stop. Day-to-day variations in roadway congestion and trip-to-trip variations in making or missing green phases at signalized intersections affect bus schedule reliability. No HCM techniques exist to predict this impact.

Pedestrians

Transit users are typically pedestrians immediately before and after their trip aboard a transit vehicle, so the quality of the pedestrian environment along access routes to transit stops affects the quality of the transit trip. Pedestrians can delay buses in the same way that they delay automobiles, as described earlier in this chapter.

Bicycles

In locations where buses pull out of the travel lane to serve bus stops, bicycles may delay buses waiting for a gap to pull back into traffic, similar to automobiles. Transit users may be bicyclists before or after their trip, so the quality of the bicycling environment along access routes to transit stops and the ability of bicyclists to bring their bicycles with them on a transit vehicle influence the quality of the transit trip.

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