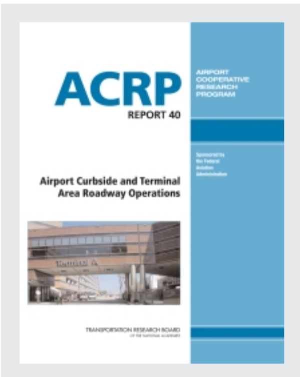

Airport Curbside and Terminal Area Roadway Operations

DETAILS

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Transportation Research Board

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 40

Airport Curbside and Terminal Area Roadway Operations

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), and the Air Transport Association (ATA) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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AUTHOR ACKNOWLEDGMENTS

The research discussed in this report was conducted under ACRP Project 07-02, "Airport Curbside and Terminal Area Roadway Operations," by a research team of recognized experts in airport planning and operations, traffic engineering, and transportation planning. LeighFisher (formerly Jacobs Consultancy) was the prime consultant. Peter B. Mandle, LeighFisher Director, was the Principal Investigator and W. Gavin R. Duncan, LeighFisher Principal Consultant, was the Deputy Principal Investigator. Other contributors from LeighFisher included Andrew Blaisdell, Dan Barton, and Tyler Tate, Consultants; and Mark Nagle, Principal Consultant. Dowling Associates was the primary subconsultant and led the research concerning roadway weaving analyses under the direction of Rick Dowling, President, and Marty Beene, Vice President. Senanu Ashiabor, a Dowling Associates Associate Engineer, also contributed. The focus groups of airline passengers were conducted by Jennifer D. Franz, President of JD Franz Research, Inc. The traffic surveys at Oakland, San Francisco, and Washington Dulles international airports were conducted by WILTEC under the direction of Moses Wilson, President. Faith Oiwa of LeighFisher coordinated the internal production and word processing of this report. Debra L. Lubin served as the technical editor.

The research team would like to express its gratitude to the members of the Project Panel for their support and insightful comments and advice throughout this research project. The research team would also like to thank the many airport staff members and consultants who took the time to review interim drafts of the Guide and provide their thoughts and comments. These reviewers included Foster de la Houassaye of Kimley-Horn Associates, Inc., and Joel Marcuson of Jacobs Engineering, both of whom served as subcontractors; John Bergener of the City and County of San Francisco (San Francisco International Airport); Michael Hackett of the Metropolitan Washington Airports Authority (Washington Dulles International and Reagan Washington National airports); Hugh Johnson of the Port of Oakland (Oakland International Airport); Keith B. Wilschetz of the San Diego County Regional Airport Authority (San Diego International Airport); James W. Green of AECOM; and M. Allen Hoffman of Ricondo & Associates, Inc.

FOREWORD

By B. Ray Derr
Staff Officer
Transportation Research Board

This guide presents a cohesive approach to analyzing traffic operations on airport curbside and terminal area roadways. The guide describes operational performance measures and reviews methods of estimating those performance measures. A quick analysis tool for curbside operations and low-speed roadway weaving areas is packaged with this guide. Techniques for estimating traffic volumes are presented as well as common ways of addressing operational problems. The guide should be useful to airport landside operators, transportation planners, and consultants analyzing airport curbside and terminal area roadway operations.

Efficient and safe roadway operations are critical to an airport's success. Key elements of an airport's roadway operations are the curbside—where travelers and their baggage enter and exit the terminal—and the terminal area roadways that provide private and commercial vehicles access to the curbside as well as to other destinations such as parking. Travelers expect safe and efficient roadway operations even as volumes increase, but the design and capacity of the curbside are often constrained by the terminal building and the proximity of on-airport landside infrastructure.

For more than 60 years, the Transportation Research Board's *Highway Capacity Manual* (HCM) has been the authoritative reference for estimating the capacity and determining the level of service for transportation facilities, including intersections and roadways. Over the decades, the HCM has grown to address additional types of facilities and better meet the needs of analysts. Although it now includes transit, bicycle, and pedestrian facilities, it does not address the unique challenges posed by airport transportation facilities. Some of these challenges are related to the tight geometrics due to limited space in the terminal area while others are due to the differences in traffic composition and traveler expectations.

In this project, LeighFisher took the first step toward creating analysis guidance comparable to the HCM for airport curbside and terminal area roadways. They surveyed the largest U.S. and Canadian airports to obtain reports from recent landside analyses. They reviewed these reports to identify analysis methods and performance measures of interest, which were then critically reviewed. A conceptual model for analyzing curbside operations and low-speed weaving areas was then developed. Field data were collected for the development of a macroscopic queuing model for curbside operations and low-speed weaving areas. The research team then wrote the guide and validated it with the project panel and staff at two airports.

The project panel believes that the guide will be practical and useful for conducting roadway analyses. The guide establishes a baseline for analysis based on the current state of the art but future additional research and experienced analysts will develop better analysis methods, much as they have for the HCM. These improvements can be incorporated into the analysis approach in the future.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Purpose, Methodology, and Organization of this Guide

ACRP Report 40: Airport Curbside and Terminal Area Roadway Operations (the Guide) is intended to assist airport operators and others in analyzing airport terminal area roadway and curbside operations. The Guide presents guidelines for estimating airport roadway requirements and capacities, recommended performance measures, valid and useful analytical methods, and potential measures to improve terminal area and curbside roadway operations.

Purpose of the Guide

This Guide is intended for use by three primary user groups. The first user group consists of airport operators, including the staff responsible for planning, design, and day-to-day operations of airport terminal area and curbside roadways. The second user group includes city, regional, and state transportation planners who may not be familiar with airport roadway operations. The third user group consists of airport consultants who are engaged to conduct planning, environmental, design, and other projects on behalf of airport operators and other sponsors. Some users may have significant experience with airports or aviation, but little familiarity with traffic engineering or transportation planning principles. Other users may have experience in traffic engineering and transportation planning, but little knowledge of airport operations. This Guide is intended to assist both groups.

For users unfamiliar with airports, the Guide describes the unique operating characteristics of airport terminal area roadways and curbside areas, and how their operations differ from those of urban streets and regional highways. The Guide presents methods for estimating existing and future airport roadway requirements and alternative methods for analyzing operations on airport roadways.

Methodology

The Guide was prepared under the direction and guidance of the project panel. The Guide reflects information gathered through an extensive literature review and the performance of more than a dozen focus groups of airline passengers, airport landside operators, and the drivers of commercial ground transportation vehicles serving airports. The definitions of curbside and weaving area levels of service included in this Guide reflect the input and comments received during the focus group sessions.

Traffic volumes gathered during a week-long survey period at Oakland and Washington Dulles International Airports were used to develop and validate new macroscopic models for analyzing and evaluating airport curbside roadway operations and low-speed weaving, as described in this Guide. The draft Guide and the macroscopic models were reviewed by representatives of these two airports and other airports.

Organization of the Guide

This Guide consists of six chapters and seven appendices (see www.TRB.org for Appendices B through G). Chapters 2 through 6 are summarized below:

- Chapter 2, Framework for Analysis of Airport Roadways and Curbsides, describes the types of vehicles and roadways typically found on airports and their unique operating characteristics. An overview is provided of (a) the hierarchy of analytical methods—quick-estimation methods, macroscopic models, and microsimulation methods—presented in Chapters 4 and 5 of this Guide—and (b) the concepts of capacity and level of service, as presented in the 2000 *Highway Capacity Manual* (HCM).
- Chapter 3, Estimating Airport Roadway Traffic Volumes, describes the data required to analyze existing roadway traffic operations and ways to gather these data. Two alternative methods for estimating future roadway requirements are presented, along with the challenges inherent in each method.

- Chapter 4, Analyzing Airport Terminal Area Roadways, presents definitions of levels of service for airport terminal area roadway operations and a hierarchy of analytical methods for analyzing terminal area roadway operations, including low-speed weaving areas, capacities, and levels of service.
- Chapter 5, Evaluating Airport Curbside Operations, presents definitions of levels of service for airport curbside roadway operations and a hierarchy of analytical methods for quickly estimating curbside roadway capacities and levels of service, including a macroscopic model—the Quick Analysis Tool for Airport Roadways (QATAR) developed during this research project.
- Chapter 6, Improving Airport Curbside and Terminal Area Roadway Operations, presents examples of commonly occurring airport curbside and roadway operational problems, describes potential improvement measures, and overviews steps for analyzing and evaluating airport roadway improvements.

The Guide also contains seven appendices as follows:

- Appendix A: Glossary of technical terms used in the Guide.
- Appendix B: Bibliography of resource documents reviewed for this research project.
- Appendix C: Summary of Terminal Area Roadway Traffic Volume Surveys conducted as part of this research.
- Appendix D: Summary of Curbside Roadway Traffic Characteristic Surveys conducted as part of this research.
- Appendix E: Summary of Focus Group Surveys of airline passengers, airport landside operators, and the drivers of commercial ground transportation vehicles serving airports conducted as part of this research
- Appendix F: A Reproduction of Portions of TRB Circular 212 presenting the Critical Movement Analysis for signalized intersections and the application of this analysis method
- Appendix G: Overview of QATAR Curbside Analysis Methodology presenting the use and application of this model as well as the spreadsheet model itself.

CHAPTER 2

Framework for Analysis of Airport Roadways and Curbsides

On-airport roadways are a unique class of roadways. Unfamiliar drivers mix with significant numbers of professionally driven large vans and buses; entrances and exits at major airports operate at near-freeway conditions, while curbside roadways operate at much slower speeds, as drivers attempt to maneuver into and out of curbside spaces. Double and triple parking and jaywalking frequently occur on curbside roadways despite the visible presence of traffic enforcement officers.

Standard highway capacity analysis procedures can address some aspects of these conditions, but not the full spectrum of operating conditions that exist on airport terminal area and curbside roadways. The various users and types of airport roadways and curbsides, and their unique operating characteristics are described in this chapter. Overviews of (1) the hierarchy of methods for analyzing airport roadway and curbside operations and (2) roadway capacity and level-of-service concepts also are presented.

Users of Airport Roadways

Airport roadways provide access to and from the multiple land uses on an airport. These roadways serve vehicles transporting airline passengers and visitors (in this Guide, "visitors" refers to meeters, greeters, and well-wishers accompanying or greeting airline passengers), employees of the airlines and other airport tenants, air cargo and mail, as well as vehicles used for the delivery of goods and services, maintenance, to support airport operations or construction, and other purposes.

A multitude of vehicle types use airport roadways. They include private vehicles, rental cars, on-demand and pre-reserved taxicabs, prearranged and on-demand limousines or Town Cars, door-to-door vans, courtesy vehicles, charter buses, scheduled buses, and service and delivery vehicles. Each vehicle/user type has its own special characteristics and affects airport roadway operations differently, as described below.

1. **Private vehicles.** Privately owned and operated vehicles consist of automobiles, vans, pickup trucks, and motorcycles used to transport airline passengers, visitors, and employees of the airport operator, airlines, and other airport tenants. Motorists transporting airline passengers in private vehicles may use the curbside areas, parking facilities (including cell phone lots), or both.
2. **Rental cars.** Rental vehicles, including automobiles and vans, used to transport airline passengers or visitors, are rented by passengers or visitors from rental car companies doing business on or near the airport for the duration of the passengers' or visitors' trips. Rental car customers may use the curbside areas, rental car ready and return areas, or both.
3. **On-demand taxicabs.** Taxicabs provide door-to-door service without prior reservations, which is typically exclusive (i.e., for a single party) and provided in vehicles capable of transporting five passengers plus their baggage. These vehicles are typically licensed and regulated by a municipal taxicab authority. Typically, on-demand taxicabs wait for deplaning passengers at a taxicab stand (or in a taxicab queue) at the curbside area next to the baggage claim area. At large airports, taxicabs may wait in a remotely located taxicab holding or staging area until they are dispatched to the curbside taxicab stand in response to customer demand.
4. **Pre-reserved taxicabs.** Pre-reserved taxicab service is exclusive, door-to-door transportation provided in vehicles capable of transporting up to five customers plus their baggage. Rather than being provided on demand, as traditional taxicab service, pre-reserved taxicabs are provided in response to prior reservations made by airline passengers seeking to be picked up by a specific company or driver, including suburban taxicabs not regulated by the municipal taxicab authority. Passengers with special needs, such as those with skis, golf clubs, large amounts of

baggage, disabilities, or passengers using a credit card to pay the fare, may request service by specific vehicles or companies. Typically, pre-reserved taxicabs or taxicabs requested specially are not allowed to wait at the curbside taxicab stand, but are assigned curb space at nearby or alternative locations.

5. **Prearranged limousines.** Prearranged limousine service is exclusive door-to-door transportation provided in luxury vehicles capable of transporting a single party consisting of up to five customers (or more in stretch limousines) regulated by a local or state agency. Generally, limousine service is only available to customers who have made prior reservations (i.e., prearranged) and are greeted (or picked up) by a driver having a waybill or other evidence of the reservations. Some airport operators allow limousine drivers to park at the curbside and wait for customers; others require that the drivers park in a parking lot or other designated zone and accompany their customers from the terminal to the parking area.
6. **On-demand limousines or Town Cars.** Privately operated on-demand door-to-door transportation is also provided by exclusive luxury vehicles or "Town Cars" capable of transporting up to five passengers and their baggage. These services are similar to on-demand taxicab services, but are provided in luxury vehicles with higher fares than those charged for taxicab services.
7. **Door-to-door vans.** Door-to-door or shared-ride van services are typically provided in vans capable of transporting 8 to 10 passengers and their baggage. The service is available on both an on-demand and prearranged basis. Passengers, who may share the vehicle with other passengers, are provided door-to-door service between the airport and their homes, offices, or other locations, but may encounter several (typically four or fewer) en route stops. Typically, door-to-door vans wait for deplaning passengers at the curbside next to the baggage claim area. Similar to taxicabs, vans may be required to wait in hold or staging areas until they are dispatched to the curbside in response to customer demand.
8. **Courtesy vehicles.** Door-to-door courtesy vehicle service is shared-ride transportation provided by the operators of hotels, motels, rental car companies, parking lot operators (both privately owned and airport operated parking lots), and others solely for their customers. Typically, no fare is charged because the cost of the transportation is considered part of, or incidental to, the primary service being provided. Courtesy vehicle service is provided in shuttle vehicles, including 8- to 12-passenger vans (e.g., those operated by small motels), minibuses, and full-size buses (e.g., those operated by rental car companies at large airports). Typically, courtesy vehicles pick up customers at designated curbside areas that have been reserved or allocated for their use.
9. **Charter buses.** Charter bus service (also referred to as tour bus or cruise ship bus service) is door-to-door service provided to a party (or group of passengers) that has made prior reservations or arrangements for the service. Charter bus and van service is provided using over-the-road coaches, full-size buses, minibuses, and vans seating more than five passengers. Since charter bus service is sporadically provided at most airports, curb space (or other passenger pickup areas) is either not allocated for charter buses or is shared with other transportation modes. Exceptions include airports serving large volumes of charter or cruise ship passengers on a regular basis. Typically, charter buses are required to wait in a remotely located hold area until the arrival or assembly of the party being provided the service.
10. **Scheduled buses.** Scheduled buses provide shared-ride service at established stops along a fixed route and operate on a scheduled basis. Typically, scheduled buses are operated by a public agency and make multiple stops along a designated route, but in some communities express or semi-express service is operated by a private operator or public agency. The location and amount of curb space allocated to scheduled buses depends on the volume of such service and the policy of the airport operator.
11. **Service and delivery vehicles.** Service vehicles include a wide range of trucks, vans, and semi-trailers, and other delivery vehicles used to transport goods, air cargo and mail, contractors, and refuse to and from the airport. Generally, deliveries are made at designated loading docks or warehouses, not at the terminal curbside. However, the pickup and drop-off locations for airline-operated small package delivery services, which are provided by small vans and light trucks, are at the terminal curbside at some airports.

Types of Airport Roadways

Although the airport passenger terminal building and surrounding area (the terminal area) is the most prominent location on an airport, depending on the size, type, and distribution of airport land uses, less than half of all traffic on an airport may be associated with passengers and visitors proceeding to/from the terminal area; the remaining traffic is generated by nonairline passenger activities, including employees. Regardless of airport size, the variety of land uses found on an airport requires a network of roadways to provide for inbound and outbound traffic, and the internal circulation of traffic between land uses. The roadway network consists of the types of roadways depicted on Figure 2-1.

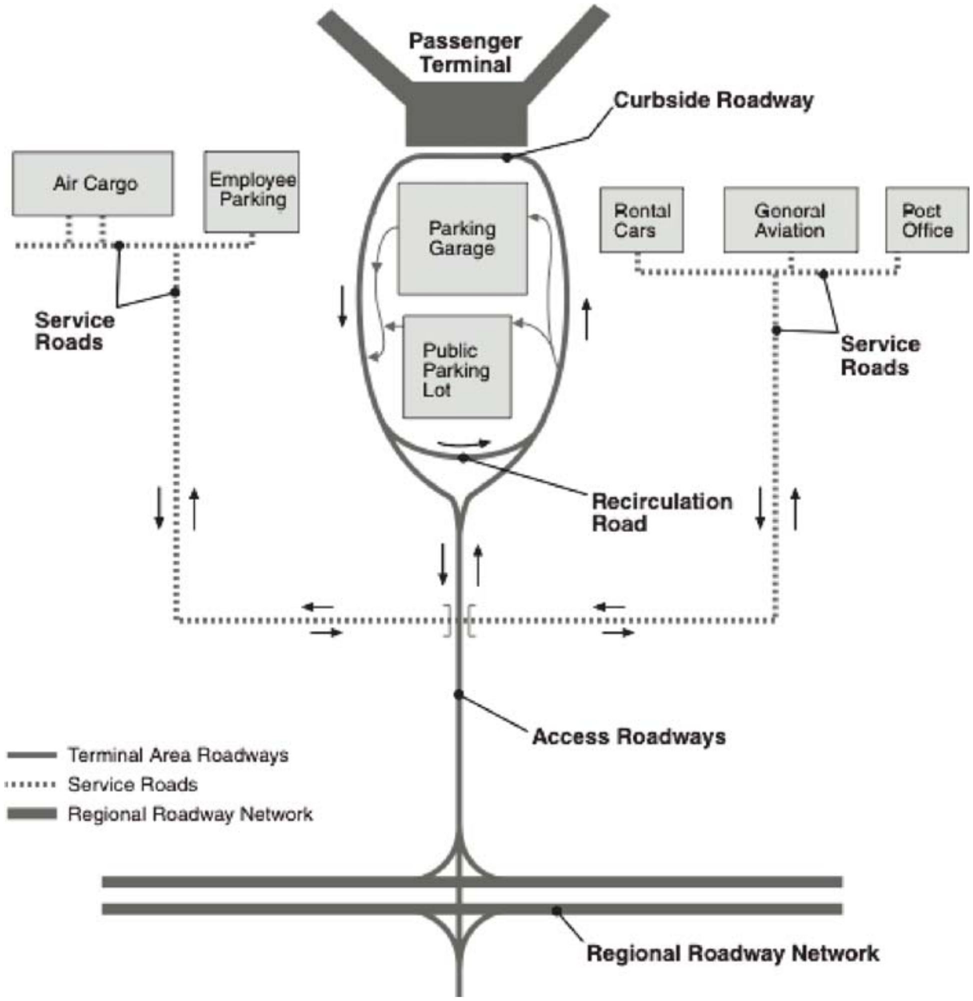


Figure 2-1. Hierarchy of airport roadway classifications.

Access Roadways

For purposes of this Guide, airport access roadways are defined as the roadways linking the regional highway and roadway network with the airport terminal and other areas of the airport that attract large volumes of airline passenger-generated traffic, such as parking and rental car facilities. Access roadways provide for the free flow of traffic between the regional network and the passenger terminal building or other major public facilities, and typically have a limited number of decision points (i.e., entrances or exits). At large airports, access roadways are often limited-access roadways with both at-grade intersections and grade-separated interchanges. At smaller airports, access roadways often have at-grade intersections that may be signalized, stop-sign controlled, or have roundabouts (yield-sign controlled).

Curbside Roadways

Curbside roadways are one-way roadways located immediately in front of the terminal buildings where vehicles stop to pick up and drop off airline passengers and their baggage. Curbside roadways typically consist of (1) an inner lane(s) where vehicles stop or stand in a nose-to-tail manner while passengers board and alight, (2) an adjacent maneuvering lane, and (3) one or more through or bypass lanes. Curb space is often allocated or reserved along the inner lane for specific vehicles or classes of vehicles (e.g., taxicabs, shuttle buses, or courtesy vehicles), particularly at the curbside areas serving baggage claim or passenger pickup.

As shown on Figure 2-2, depending on the configuration of the adjacent terminal building, curbside roadways may include one, two, or more vertical levels and/or one, two, or more parallel roadways separated by raised medians (often called islands). At airports with dual-level curbsides, the upper level curbside area is at the same level as airline passenger ticketing and check-in facilities inside the terminal and is intended for passenger drop-off. The lower level curbside area is at the same level as the baggage claim area and is reserved for passenger pickup. At airports with multiple terminals where one of the parallel roadways serves as a bypass roadway, cut-through

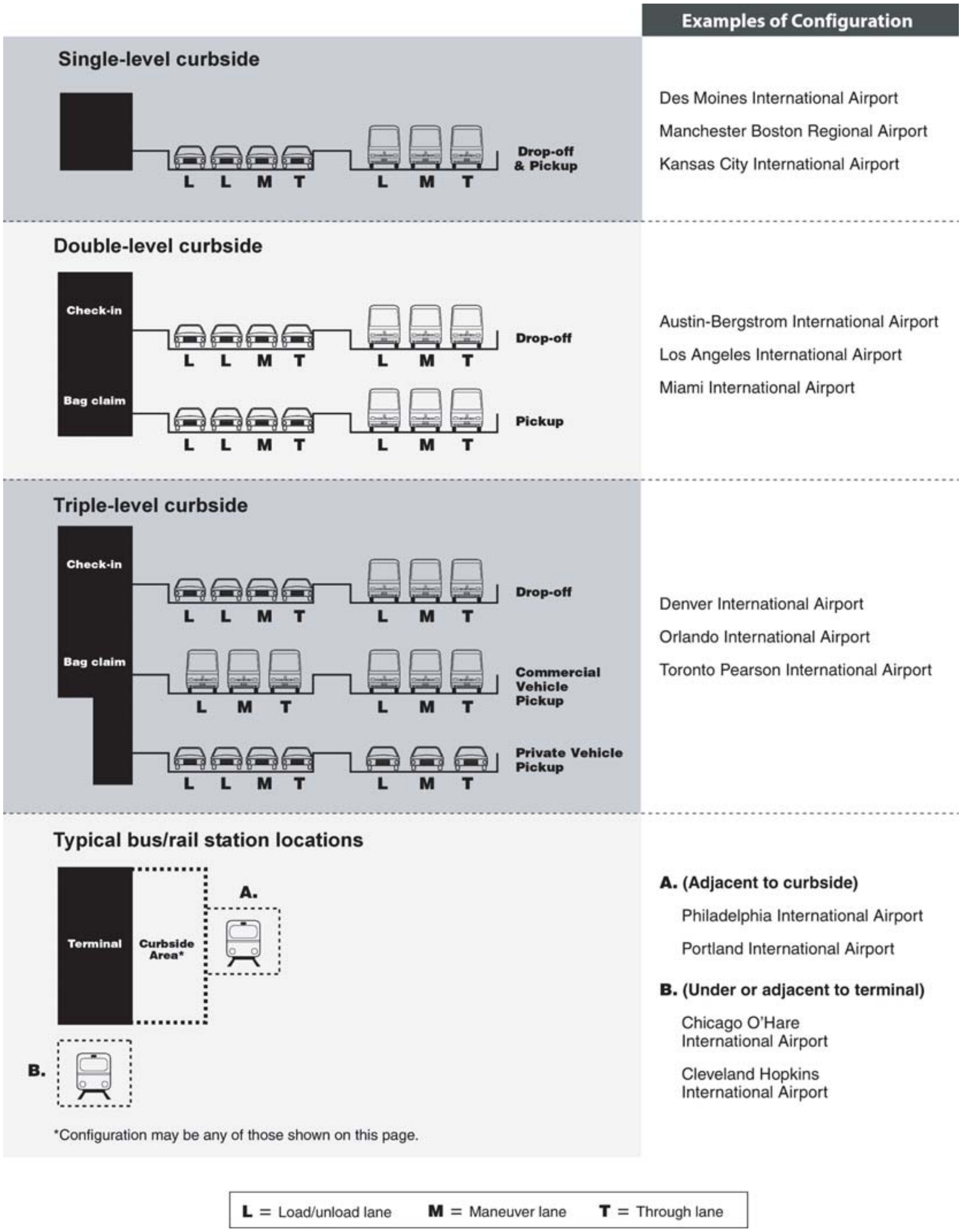


Figure 2-2. Typical airport curbside configuration.

roadways may be provided to allow vehicles to circulate between the inner and outer parallel roadways (and curbside roads).

Circulation Roadways

Circulation roadways generally serve a lower volume of traffic and are less direct than the roadways served by access roadways. Circulation roadways often provide a variety of paths for the movement of vehicles between the terminals, parking, and rental car facilities. Examples include return-to-terminal roadways that allow motorists to proceed to parking after having dropped off airline passengers (or proceed from parking to the terminals) and allow courtesy or other vehicles to return to the terminal (e.g., after having dropped off enplaning airline passengers and returning to pick up deplaning passengers on a different curbside roadway). Compared to access roadways, circulation roadways typically operate at lower speeds and allow for multiple decision points.

The above roadways—access roadways, curbside roadways, and circulation roadways—are considered "curbside and terminal area" roadways and are the focus of this Guide. Other airport roads include service and access roads, as described below.

Service Roads

Service roads link the airport access roadways with on-airport hotels, employee parking areas, and employment centers (e.g., aircraft maintenance facilities or hangars), air cargo/air freight buildings and overnight parcel delivery services, loading docks/trash pickup areas, post offices, fixed-base operators (FBOs) or general aviation areas, airport maintenance buildings and garages, military bases, and other nonsecure portions of the airport that generate little airline passenger traffic.

The traffic generated by these land uses differs from that generated by the passenger terminal building in several respects. First, the traffic on service roads includes a higher proportion of trucks, semi-trailers, and other heavy vehicles than the traffic on curbside and terminal area roadways, which rarely serve trucks or delivery vehicles. Second, most drivers on the service roads (e.g., employees and drivers of cargo vehicles) use these roads frequently and are familiar with the roads and their destinations, unlike drivers using the curbside and terminal area roadways.

For purposes of operational analyses, the service roads are similar to those found in an industrial park. Typically, they consist of two- to four-lane roads with generous provision for the turning paths of large trucks and semi-trailers and for entering and exiting vehicles, including separate or exclusive turning lanes.

Airfield Roads

A separate network of roads located within the aircraft operating area or the airfield is used by ground service equipment, including vehicles servicing aircraft, towing aircraft, or towing baggage carts and vehicles used for runway maintenance or emergency response. Often these vehicles are not licensed to operate on public streets. Only drivers with airfield licenses are permitted to operate vehicles with aerodrome permits in secure or restricted areas. The design and operation of these roads is addressed in guidelines issued by the FAA Series 150 Advisory Circulars

The remainder of this Guide addresses curbside and terminal area roadways only.

Operating Characteristics of Airport Terminal Area Roadways

The operating characteristics of airport terminal area roadways differ from those of other public roads. This section describes the distinguishing operating characteristics of airport terminal area roadways, weaving sections, and curbside areas.

What Makes Airport Roadway Operations Unique

The main differences between the operating characteristics of airport terminal area access and circulation roadways and nonairport roadways include

- **A high proportion of unfamiliar motorists.** Because most airline passengers fly infrequently (e.g., fewer than four times per year), they (and the drivers who are dropping them off/picking them up) are not familiar with the roadways at their local airport(s), much less the roadways at their destination airport(s). Unlike commuters, who rarely need to refer to roadway signs, airline passengers rely upon signs (or other visual cues) to guide them into and out of an airport and to/from their destinations on the airport. Picking up passengers may be particularly challenging for unfamiliar motorists, who must follow the appropriate signs, be aware of all the traffic and pedestrian activity at the curbside areas, and also be able to identify their party among crowds of other passengers waiting to be picked up.
- **Large number of complex directional signs.** Directional signs on airports often provide more information (i.e., more lines of text) than those on public roadways governed by the *Manual of Uniform Traffic Control Devices* (published by FHWA) because of the number of terminals, separation of departures and arrivals level roadways, airlines, parking options, and rental car companies that must be provided to motorists (see Figure 2-3). For example, the general policy at U.S. airports is to display the name of every airline serving an airport, even those operating only a few times a week. The signs often include colors, fonts, symbols, and messages not used on other public roadway signs.

  Because of the number, size, and complexity of these signs, motorists may not see regulatory or warning signs concerning height restrictions, parking rates, security regulations, use restrictions (e.g., authorized vehicles only), and other messages. These signs may result in an overload of information and cause motorists to decelerate while attempting to read the signs.
- **Stressful conditions.** Motorists operating on airport roadways are under more stress than typical motorists. This stress results from the knowledge that minor delays or

Source: LeighFisher.

Figure 2-3. Complex airport roadway signs.

wrong turns may cause a person to arrive too late to check baggage, claim a pre-reserved seat, or greet an arriving passenger, or in an extreme case, miss a flight entirely. Congested airport roadways, closely spaced decision points, and complex signs can add to this stress and discomfort.

Factors adding to passenger stress at an airport include the need to connect from a car to a plane, from a car to a bus, find a parking place, find a passenger ("Where is Aunt Meg?"), find the correct place to drop off or pick up a passenger, locate the taxicab, courtesy vehicle, or city bus stop, and so forth. Passengers realize the importance of making correct decisions in an environment that is more complicated and anxiety-filled than a typical roadway situation so that they do not miss their flights or rides. Each action on an airport is part of a chain of events, any one of which can go wrong and disrupt or delay a vacation, business meeting, or other important event.

- **High proportion of large vehicles.** More than 10 types of ground transportation services operate on airport roadways. The characteristics of each service, the needs of the customers using the services, and the operating characteristics of the vehicles used to provide these services must be considered when developing physical and operational plans for airport curbside and terminal area roadways.

  Courtesy vehicles, door-to-door vans, scheduled buses, and other large vehicles may represent 10% to 20% of the traffic volume on a terminal area roadway. On a typical public street, less than 10% of the traffic consists of large vehicles. Standard *Highway Capacity Manual* (HCM) capacity calculation procedures reduce the capacity of a public highway with a high percentage of truck, bus, and other large vehicle traffic to account for the slower acceleration/deceleration characteristics of these vehicles.

  However, the use of a capacity adjustment factor may not be necessary on airport terminal area roadways because courtesy vehicles, vans, and buses operating on those roadways do not interfere with the flow of other traffic to the extent that they do on public highways. On airport terminal area roadways, these large vehicles can operate at the range of prevailing speeds typically found on airport roadways (i.e., 25 miles per hour [mph] to 45 mph) and have sufficient power to accelerate and decelerate at rates that are comparable to those of private vehicles—and do so unless they are transporting standing passengers—because most airport roadways are level or have gentle vertical slopes. Additionally, large vehicles such as courtesy vans or shuttle buses may obstruct motorists' views of wayfinding signs and may interfere with the operation of passing vehicles as they enter or exit curbside areas.
- **Mix of experienced and inexperienced drivers.** Although most private vehicle drivers use an airport infrequently, 20% to 30% of the vehicles on airport roadways are operated by professional drivers who are thoroughly familiar with the on-airport roadways because they use them frequently—perhaps several times each day. This difference contributes to vehicles operating at a range of speeds on the same roadway segment—slow-moving vehicles (e.g., unfamiliar drivers of private vehicles attempting to read signs or complete required turns and maneuvers) and faster vehi-

cles (e.g., taxicabs and limousines operated by professional drivers familiar with the airport roadways and who may ignore posted speed limits).

- **Recirculating traffic.** Traffic officers often require motorists to exit the terminal area if they are not actively loading or unloading passengers, unable to find an empty curbside space, or waiting for an arriving passenger who is not yet at the curbside. Motorists exiting the curbside area may either wait in a cell phone lot until the passenger arrives (which is encouraged by airport operators) or recirculate around the airport and back to the curbside. Table 2-1 indicates the percentage of roadway traffic that recirculates past the terminal more than once.

These recirculating vehicles contribute to roadway congestion and represent unnecessary traffic volumes. Factors contributing to recirculating roadway traffic include (1) stricter enforcement procedures required by current security regulations, (2) motorists who may not understand the difference between the published flight arrival time and the time when a passenger arrives at the curbside, (3) motorists waiting for passengers whose flights have been delayed, and (4) drivers of commercial vehicles who, in violation of airport regulations, are improperly soliciting customers along the curbside roadway.

What Makes Airport Roadway Weaving Section Operations Unique

Weaving is defined as the crossing of two or more traffic streams traveling in the same direction along a length of highway without the aid of a traffic signal or other control device. A weaving maneuver occurs when vehicles enter a roadway segment from one side and exit the segment on the other while other vehicles do the opposite at the same time. The most common example of weaving occurs on freeways where an on-ramp is followed by an off-ramp a short distance later, and those two ramps are connected by an auxiliary lane. The weaving movement occurs when vehicles on the freeway move into the auxiliary lane to exit via the off-ramp, while vehicles from the on-ramp move from the auxiliary lane onto the freeway.

Table 2-1. Percentage of private vehicles recirculating to the arrivals curbside.

Airport	Recirculating (%)
Baltimore/Washington International Thurgood Marshall Airport	50%
San Francisco International Airport	43%
Seattle-Tacoma International Airport	30%
Dallas Love Field	26%
Reagan Washington National Airport	15%

Source: Based on data provided by Ricondo & Associates, Inc., June 2009.

The operation of weaving and merging areas on airport roadways differs from the operation on nonairport roadways primarily because these operations occur at slower speeds on airport roadways than they do on freeways and arterial streets. Weaving analyses generally are conducted for freeways and arterial streets on which vehicles operate at higher speeds than those on most airport roadways. At high speeds, drivers require large gaps between successive vehicles in order to merge into, or weave across, a traffic stream. In the 2000 HCM, it was assumed that a free-flow speed of 35 mph on a weaving section represents level of service (LOS) E (i.e., operations at or near a roadway's capacity—the HCM chapters on weaving and merging were prepared for freeways). Thus, the metrics used in the HCM to establish satisfactory weaving conditions are not suitable for analysis of airport roadways, which operate at lower speeds than freeways. Chapter 4 of this Guide presents alternative metrics and analysis methods for use on airport roadways.

Upon entering an airport, motorists typically encounter a series of exits or turns leading to nonterminal areas (e.g., economy parking, air cargo, general aviation), close-in parking (hourly, daily, or valet) and rental car return (by company), and ticketing/departures vs. baggage claim/arrivals curbside areas. Upon exiting the airport, motorists may encounter a similar series of exits as well as roads leading back to the terminal and alternative regional destinations.

Often, the distance between successive decision points is much less than that suggested by highway design standards established for limited access highways because of the relatively short distances available between an airport entrance and the terminal area. Unlike a regional highway where decision points may be separated by a mile or more, successive decision points on an airport may be separated by 500 feet or less. Even though motorists on airport roadways are traveling at speeds (e.g., 35 mph or less) that are slower than those on freeways or arterial roadways, the limited distances between decision points compromise the ability of motorists to recognize, read, and react to roadway guide signs, or do not allow adequate time to complete required merging and weaving maneuvers.

What Makes Airport Curbside Operations Unique

As noted in Chapter 1, curbside roadways consist of the inner curbside lane(s) where vehicles stop or stand typically in a nose-to-tail arrangement while passengers board and alight, an adjacent maneuvering lane that vehicles may occupy while decelerating or accelerating to enter or exit the curbside lane, and one or more "through" or bypass lanes. The operating characteristics of airport terminal curbsides differ significantly from those of most other roadways because of the interactions between vehicles maneuvering into and out of curbside spaces and vehicles traveling in the through or bypass lanes.

The capacity of a curbside roadway is defined both by the number of vehicles that can be accommodated while stopping to pick up or drop off passengers and the number that can be accommodated while traveling past the curbside in the through lanes. The capacity of the through lanes is restricted by vehicles that are double parked (which is often tolerated on airport curbside roadways) or triple parked. These capacity restrictions can cause traffic delays and the formation of queues that block vehicles trying to maneuver around stopped vehicles or attempting to enter and exit curbside spaces. (Additional information on the operating characteristics of curbside roadways is presented in Chapter 5.)

The length (or capacity) of a curbside area must be in balance with the capacity of the through lanes drivers use to enter and exit the curbside area. For example, a mile-long curbside served by only two lanes (one curbside lane and one through lane) would be imbalanced because, even though the curb length could accommodate a large number of vehicles, traffic flow in the single through lane would be delayed every time a vehicle maneuvers into and out of a curbside space or double parks waiting for an empty space. The reverse imbalance would occur with a very short curbside area and multiple through lanes.

Other operating characteristics of airport curbside roadways that differ from public roads, as further described in Chapter 5, include the following:

- **Dwell times.** The length of time a vehicle remains stopped at the curbside area is referred to as "dwell time." Generally, vehicles transporting a large number of passengers and baggage require a long dwell time. The number of vehicles that can be accommodated along a given curbside length is determined by the size of the vehicles (i.e., the length of the stall each vehicle occupies, including maneuvering space in front of and behind the vehicle) and the amount of time each vehicle remains at the curbside (i.e., the dwell time). Dwell times at a particular airport are affected by enforcement policies (i.e., strict enforcement leads to shorter dwell times) and local driver behavior (e.g., do drivers double park in a way that allows other motorists to easily enter and exit the lane adjacent to the terminal?).

  Motorists dropping off passengers typically have shorter dwell times than those picking up passengers (unless motorists are prohibited from waiting for the arrival of a deplaning passenger). Thus, since airports generally have equivalent volumes of originating and terminating airline passengers (and associated traffic volumes), the required capacity or length of an arrivals (pickup) curbside area is typically greater than that of the departures (drop-off) curbside area.
- **Maneuvering traffic and parking preferences.** Unlike motorists on city streets, motorists parallel parking at airports rarely back into a curbside space. Motorists frequently stop with their vehicles askew to the travel lanes or sidewalk areas rather than maneuvering their vehicles into positions parallel to the curbside. By doing so, they may block or interfere with the flow of traffic in other lanes. Motorists leave space between successive vehicles to assure that they are not blocked and to allow access to the trunk or baggage storage area.

  Motorists using airport curbside roadways may stop in the second lane even if there is an empty space in the curbside lane to avoid being blocked in by other motorists and to reduce the walking distances of passengers being dropped off (e.g., stop near a desired door or skycap position) or being picked up (e.g., stop at a point near where the person is standing). Thus, motorists frequently stop in the second lane in front of the door serving the desired airline even though there may be an empty curbside space located downstream. The propensity to avoid inner lanes and double park reflects local driver behavior or courtesy.
- **Capacity of adjacent through lanes.** Through-lane capacity is reduced by traffic entering and exiting curbside spaces, high proportions of vehicles double and triple parking, the use of the maneuver lanes, and other factors. As such, the capacity analysis procedures presented in the 2000 HCM are not applicable. Chapter 5 of this Guide presents suggested methods for calculating the capacities of curbside lanes and through lanes at airports.
- **Uneven distribution of demand.** Curbside demand is not uniformly distributed during peak periods, reflecting (1) airline schedules and (2) the uneven distribution of the times passengers arrive at the enplaning curbside prior to their scheduled departures (lead time) or the times passengers arrive at the deplaning curbside after their flights have landed (lag times). Furthermore, stopped vehicles are not uniformly distributed along the length of a curbside area, reflecting motorist preferences for spaces near specific doors and skycap positions and their aversion to spaces near columns or without weather protection, if weather-protected spaces are available.

  An aerial view of a busy terminal curbside area would show vehicles stopped adjacent to the door(s) serving major airlines. When a new terminal is opened, the airline with the largest market share frequently gets the first choice of ticket counter and baggage claim area locations. Often, this airline selects the most prominent location, which generally is the area nearest the entrance to the curbside area. Thus, curbside demand is often heaviest at the entrance to the curbside area, causing double-parked vehicles and congestion in this area, while downstream areas remain unoccupied.

- **Allocation of space for commercial vehicles and other uses.** At most airports, curb space is allocated to commercial vehicles on the pickup curbside area. In the allocation of commercial vehicle curb space, multiple factors must be considered in addition to calculated space requirements, such as customer service, operational needs, airport policies, revenues, and perceived or actual competition among ground transportation services. Curb space may also be allocated for disabled parking, police vehicles, airport vehicles, valet parking drop-off/pickup, tow trucks, and other users.
- **Allocation of traffic on inner and outer curbside areas.** At airports having inner and outer curbside areas, one curbside area is generally allocated for private vehicles and the other curbside area(s) is (are) allocated for commercial vehicles. It may be difficult to direct private motorists—especially those unfamiliar with the airport—to multiple curbsides (or supplemental curbsides) and, as such, supplemental curbsides are rarely used. Conversely, it is fairly common to direct commercial vehicles to multiple curbside areas.
- **Crosswalk location, frequency, and controls.** Crosswalks provide for the safe movement of pedestrians between the terminal building and center island curbside areas or a parking facility located opposite the terminal. The use of crosswalks can be encouraged and jaywalking discouraged by providing numerous crosswalks at convenient (i.e., closely spaced) locations and/or fences or other barriers to pedestrians along the outer island.

  However, providing multiple crosswalks adversely affects the flow of through traffic. Motorists are often required to stop at more than one crosswalk because traffic controls at the crosswalks (whether traffic officers or signals) are rarely coordinated in such a way as to allow a continuous flow of through vehicles, such as commonly occurs on an urban street. Multiple crosswalks also reduce the available length of curb space. A single crosswalk has less impact on through traffic and available curb length than multiple, unsignalized crosswalks, although multiple crosswalks are more convenient.
- **Curbside lane widths.** At most airports, curbside roadway lane widths are the same as those on public streets (e.g., 10 to 12 feet). Recognizing the tendency of drivers to double park, some airport operators have elected to delineate one double-wide (e.g., 20 to 24 feet) curbside lane rather than two adjacent 10- to 12-foot lanes. (See Figure 2-4.)
- **Availability of short-duration parking.** Curbside demand can be influenced by the availability and price of conveniently located, short-duration (e.g., hourly) parking. If such parking is readily available and reasonably priced, fewer motorists may choose to use the curbsides. Conversely, the perceived lack or high cost of available short-duration parking spaces can discourage motorists from parking and instead lead to increased curbside demand. Similarly, the availability of cell phone or call-and-wait lots can reduce curbside roadway traffic volumes.

Source: LeighFisher.

Figure 2-4. Double-wide curbside lane at Washington Dulles International Airport.

- **Multiterminal airports.** Large airports may have multiple terminals, each with separate curbside areas, or continuous curbsides that extend between terminal buildings. Curbside operations at each terminal may differ, reflecting the characteristics of the dominant passenger groups and airlines (e.g., international vs. domestic passengers, or legacy vs. low cost carriers).
- **Recirculating or bypass traffic.** At many airports, there is a significant proportion of nonstopping or bypass traffic on the terminal curbsides. This bypass traffic includes (1) recirculating traffic that, because of police enforcement or other reasons, passes the terminal curbside (particularly the deplaning curbside) more than once, (2) curbside traffic destined for another terminal or adjacent curbside section, which must bypass the curbside in question, and (3) noncurbside traffic traveling past the curbside (e.g., cut-through vehicles, employee vehicles, or airport service or maintenance vehicles).
- **Nonstandard curbside configurations.** Although most airports have linear curbsides where vehicles stop bumper to bumper or nose to tail, a few airports have nonstandard curbside configurations.
  - **Pull-through private vehicle spaces.** As shown on Figure 2-5, the curbside areas at some U.S. airports (e.g., Lambert-St. Louis International, Nashville International, and Little Rock National Airports), as well as many overseas, have (or had) pull-through spaces arranged at 45-degree angles that allow motorists to pull through, similar to the way they would at a drive-through window.

Source: LeighFisher.

Figure 2-5. Pull-through curbside lanes at Brussels Airport.

Source: LeighFisher.

Figure 2-7. Pay for curbside use at Paris Charles de Gaulle International Airport.

- **Angled commercial vehicle spaces.** The commercial vehicle curbside areas at the airports serving Atlanta, Newark, and Orlando, among others, have angled spaces that require vehicles to back up to exit.
- **Driver-side loading.** As shown on Figure 2-6, at a few airports (e.g., Bush Intercontinental Airport/Houston and Mineta San Jose International Airport), the deplaning curbsides are located on the driver's side of the vehicle, requiring private vehicle passengers to open the door and enter or exit the vehicle on the side away from the terminal building while standing in a traffic lane. Driver-side loading is used at some airports for taxicabs because passengers may enter the cab from either side of the vehicle.
- **Brief parking zones—pay for curbside use.** Some European airports do not provide free curb space, but instead provide parking areas adjacent to the terminals that motorists can use for a fee. These areas can be configured parallel to the curbside (see Figure 2-7) or in a traditional parking lot adjacent to the terminal building (see Figure 2-8). In Europe, unattended vehicles are permitted in these zones, but in the United States, current security regulations prohibit unattended vehicles at the terminal curbsides.
- **Supplemental curbsides.** Some airports provide supplemental curbsides in or near parking structures or at remotely located sites. Examples of airports with curbside areas within parking structures include those at the airports serving New York (LaGuardia), St. Louis, and Salt Lake City (see Figure 2-9).

Source: LeighFisher.

Figure 2-6. Driver-side loading at Mineta San Jose International Airport.

Source: LeighFisher.

Figure 2-8. Brief parking curbside zone at Munich Airport.

Source: LeighFisher.

Figure 2-9. Supplemental curbside at Salt Lake City International Airport.

The analytical procedures described in this Guide are most relevant for airports with traditional curb spaces because of the differing dwell times and through-lane operations that occur with other configurations.

Overview of Analytical Framework Hierarchy

Subsequent chapters of this Guide present alternative methods for analyzing airport roadways, weaving sections, and curbside areas, recognizing the unique characteristics of these facilities. The alternative analysis methods or hierarchy differ in terms of (1) the level of effort or time needed to conduct the analysis, (2) the expected level of accuracy or reliability of the results, and (3) the necessary level of user skill or experience. The three methods—quick-estimation methods, macroscopic methods, and microsimulation methods—are described in the following paragraphs.

Quick-Estimation Methods

Quick-estimation methods, as the name suggests, can be used simply and rapidly to produce preliminary analyses of roadway operations (or other facilities). They generally consist of look-up tables, simple formulas based on regression analysis of databases, or rules of thumb, and are based on broad assumptions about the characteristics of the facility being analyzed. As such, they provide a first test of the ability of a roadway or other facility to properly accommodate the estimated requirements (existing or future) or the adequacy of a potential improvement measure.

Quick-estimation methods are ideal for quickly sizing a facility. The analyst can easily check which of many possible roadway design options is sufficient to serve the forecast demand. These methods, however, are less than satisfactory for estimating the operating performance of a given roadway or for refining a given design. If information on the actual performance of a given facility or how to refine a particular design is desired, then macroscopic methods (described below) should be used.

Macroscopic Methods

Macroscopic methods are used to consider the flows of vehicle streams, rather than the flows or operations of individual vehicles. The HCM is an example of a set of macroscopic methods for evaluating roadway operations. As such, these methods approximate the interactions between individual vehicles, the behavior of individual drivers, and detailed characteristics of the roadways (or other facilities). Adjustment factors, typically developed through empirical observations or microsimulation methods, often are used to account for atypical vehicles or driver characteristics, traffic flow constraints, or other operational characteristics. These methods produce results that are considered acceptable, more accurate than quick-estimation methods, and can be used with less training and experience than microsimulation methods.

Macroscopic methods can provide reliable estimates of the steady-state performance of a roadway averaged over a given analysis period. They are best for determining the refinements to a proposed design (or existing facility) that would eliminate capacity and congestion problems. These methods are less satisfactory for quantifying facility operations under heavy congestion conditions.

Macroscopic methods are generally unsatisfactory for comparing alternative improvements that reduce but do not eliminate congestion. Under heavily congested conditions (hourly demand exceeding capacity), queuing vehicles from one part of the roadway affect both upstream and downstream operations in a manner that cannot be estimated easily using macroscopic methods. Macroscopic methods also cannot be used for unusual facility types or situations for which they were not designed. In those situations, microsimulation methods must be used.

Microsimulation Methods

Microsimulation methods consist of the use of sophisticated computer programs to simulate the operation of individual vehicles on simulated roadway networks. Each vehicle is assigned characteristics, such as a destination, performance capabilities, and driver behavior. Each roadway network is defined using characteristics such as number, length, and width of lanes; operating speeds; traffic controls; and pedestrian activity. As each imaginary vehicle travels through the computerized roadway network, various aspects of its performance can be recorded based on its interaction with other vehicles and traffic controls. These performance statistics can be summarized in many ways, including commonly used performance measures, such as travel time and delays, travel speeds, and queue lengths. Also, some microsimulation models produce a visual display of the simulated roadway operations, which can be helpful when evaluating operations or presenting results.

Of the three methods for analyzing airport roadway conditions, microsimulation methods are the most complex and require the most effort and skill on the part of the user, but they also produce the most detailed and reliable results. The use of microsimulation methods is suggested when macroscopic methods do not yield reasonable results, do not provide sufficient detail, or when the conditions being analyzed are outside the ranges addressed by macroscopic methods.

Additional information regarding the application of these three analysis methods is presented in subsequent chapters of this Guide.

Overview of Capacity and Level-of-Service Concepts

The concepts of capacity and level of service, as presented in the 2000 HCM, are fundamental to analyses of roadway and other transportation facilities and well understood by traffic engineers and transportation planning professionals. This section is intended to provide an overview of these concepts for users not familiar with the 2000 HCM.

Capacity Concept

The capacity of a rectangle or a box can be defined easily by its size (i.e., its area or volume) because the maximum amount the object can accommodate is fixed. This is not true with objects that serve as "processors," such as roadways, ticket counters, or runways. The capacity of a roadway, for example, depends not only on its size (e.g., the number of lanes and other geometric design aspects), but also on the characteristics of the vehicles using the roadway (e.g., their size, performance, spacing, speed, and many other operating characteristics). If all the vehicles on a roadway were identical in size, distance apart, speed, driver characteristics, and other characteristics, then the capacity of the roadway (number of vehicles traversing a point or section during a unit of time) would be expected to be substantially higher than the capacity of the same roadway if it were serving a mix of vehicle sizes, speeds, and driver characteristics.

Accordingly, the capacity of a roadway—even roadways with the same number of lanes—varies based both on the characteristics of the roadway (e.g., lane and shoulder widths, vertical grades, intersection and driveway spacing, and traffic control types) and the characteristics of the vehicles and drivers using the roadway (e.g., the proportion of trucks or heavy vehicles, daily and hourly variations in use, familiarity of the typical drivers with the roadway). With knowledge of the characteristics of a roadway section and the vehicles (and drivers) using the roadway, it is possible to calculate its capacity—the "maximum hourly rate" of vehicles flowing past a point.

However, it is not possible or desirable for a roadway to operate at its capacity for sustained periods, because any minor disruption will cause congestion, which results in delays or lengthy queues and undesirable levels of safety and driver comfort. Thus, roadway capacity, while stated in terms of "base" vehicles (e.g., passenger car equivalents) per hour, is sometimes computed for only the peak 15-minute flow rate within that hour. In addition, roadway operations are characterized in terms of level of service and "service flow rate"—the maximum flow rate that can be accommodated while maintaining a designated level of service. Similar to capacity (maximum hourly vehicle flow rates), service flow rates vary according to the characteristics of a roadway section and the vehicles using the roadway.

Level-of-Service Concept

Level of service is a qualitative measure of roadway (or other transportation facility) operations. Six levels of service are defined in the 2000 HCM, with LOS A representing the highest (or best) level of service and LOS F representing the lowest (or worst) level of service. The 2000 HCM defines level of service as follows:

> . . . a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Levels of service are defined in terms of parameters that can be perceived by the users of a transportation facility and that can be measured and predicted. On roadways, each level of service corresponds to a specific maximum flow rate (i.e., the upper limit of the performance measure threshold (or flow rate)) for that level of service. The parameters or measures of effectiveness defining each level of service are (1) the density of the traffic flow (passenger cars per mile per travel lane) for a freeway or other unsignalized multilane roadway and (2) delay (seconds per vehicle) for signalized and unsignalized intersections.

Commonly Used Level-of-Service Definitions for Airport Terminal Area Roadways

As noted, the 2000 HCM defines six levels of service, as presented below. (These definitions were taken from the 2000

HCM, but have been modified slightly for the benefit of airport planners and others not familiar with the HCM.)

LOS A represents operations where free-flow speeds prevail. The ability of each driver to maneuver within the traffic stream, change lanes, merge, or weave is almost completely unimpeded by other vehicles because of low traffic densities. The effects of transient blockages or incidents (e.g., an accident, vehicle breakdown, or other event that impedes the flow of traffic) are easily absorbed at this level of service.

LOS B represents conditions in which free-flow speeds are maintained. The ability of each driver to maneuver within the traffic stream, change lanes, or weave is only slightly restricted by the presence of other vehicles. The general physical and psychological comfort of drivers is still high. The effects of minor incidents and point breakdowns (e.g., a breakdown in traffic flow where traffic enters, leaves, or crosses a roadway) are still easily absorbed.

LOS C represents traffic flow with speeds at or near the free-flow speeds of the roadway. Freedom to maneuver within the traffic stream is noticeably restricted (by the presence of other vehicles) and lane changes may require more care and vigilance on the part of the driver because of high traffic densities. Minor blockages or incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage. On airport roadways, LOS C is generally considered to be the minimum "acceptable" level of service because of the lack of alternative travel paths and the significant negative consequences of travel delays.

LOS D represents the level at which speeds begin to decline slightly with increasing flows, and density (on freeways and other roadways with uninterrupted flows) begins to increase somewhat more quickly. Freedom to maneuver within the traffic stream is more noticeably limited (because of the lack of gaps between successive vehicles), and the driver experiences reduced physical and psychological comfort. Even minor blockages or incidents can be expected to quickly create queues because the traffic stream has little space to absorb disruptions.

LOS E represents operations at or near capacity. Operations at this level are volatile because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced, leaving little room to maneuver (or allow for lane changes or weaving) within the traffic stream. Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can disrupt upstream traffic flows. At capacity, the traffic stream has no ability to absorb even the most minor disruptions, and any incident can be expected to produce a serious breakdown with extensive queuing. Maneuverability within the traffic stream is extremely limited and the level of physical and psychological comfort afforded the driver is poor.

LOS F represents breakdowns in vehicular flow. Such conditions generally exist within queues forming behind bottleneck points. Bottlenecks occur as a result of (1) traffic accidents or incidents, (2) typical traffic congestion areas, such as lane drops, weaving segments, or merges, (3) parking maneuvers, or (4) traffic conditions when the projected hourly flow exceeds the estimated capacity of the roadway segment.

Acceptable Levels of Service for Terminal Area Roadways

As noted, levels of service are typically used to determine if a roadway can properly accommodate existing or future traffic operations or compare alternative improvement options. On regional freeways and arterials and in densely developed urban areas, LOS D is often considered acceptable because motorists traveling on regional roadway networks can select alternative travel paths should their preferred path be congested. However, on airport roadways, where only a single path is available (and the cost of delay to the traveler is great), LOS C is typically considered to be the minimum acceptable level of service because of the lack of alternative travel paths and the significant negative consequences resulting from travel delays (e.g., passengers missing their flights).

CHAPTER 3

Estimating Airport Roadway Traffic Volumes

This chapter presents methods for estimating existing and future airport roadway requirements. The data required to analyze existing roadway traffic volumes and operations are described, and two alternative methods for estimating future roadway traffic volumes are presented. One method, the traditional four-step approach commonly used by transportation planners, incorporates estimates of the roadway traffic volumes generated by airline passengers, visitors, employees, air cargo handlers, and major airport land uses. This method requires an extensive database for each of these traffic generators. The second method, the growth factor method, yields acceptable, but less precise results, while requiring much less input data. However, this simpler method is less sensitive to changes in future conditions or travel patterns.

Establishing Existing Airport Roadway Traffic Volumes

Analyses of existing conditions and estimates of future conditions should be based on observed vehicular activity. Surveys of traffic volumes, roadway operations, and vehicle characteristics are often conducted to support these analyses. Additional information about traffic surveys can be found in the ITE *Manual of Traffic Engineering Studies* and other references listed in the bibliography provided in Appendix B to this Guide.

Roadway Traffic Volume Survey Methods

Roadway traffic volumes can be obtained inexpensively and quickly through surveys compared to a planning and forecasting analysis. Surveys of roadway traffic can be conducted by (1) the public works or traffic engineering department of a municipality or county using automatic traffic recorders (ATRs), (2) consulting firms that specialize in conducting such surveys, or (3) interns, students, or volunteers recruited to manually record traffic volumes on airport roadways. For example, in 2010 a comprehensive 7-day traffic survey that included installing ATRs at 25 locations typically cost less than $50,000 (or about $1,000 to $2,000 per location) excluding any analyses of the resulting data.

If the analysis of roadway operations is to focus on one roadway segment (e.g., a curbside roadway), it may be necessary to record only the traffic volumes on this segment and/or adjacent roadways rather than to conduct a comprehensive survey of all roadways. Similarly, if peak airport traffic periods are known, it may be possible to record the traffic volumes during a 3-hour peak period coinciding with this peak period rather than conduct day-long, 48-hour, or 7-day surveys.

Selecting Survey Dates

Ideally, the traffic volume and curbside surveys should be conducted during the peak hours on a typical busy day (ideally during a peak month). Typically, the peak days occur in the months with the largest volumes of airline traffic. At many airports, the busiest days are Mondays and Fridays, but at some airports—especially those serving large volumes of non-business passengers—the busiest days may be Sundays.

Selecting Survey Hours

The peak hours for roadway traffic precede the peak hour for originating airline passenger departures and follow the peak hour for terminating airline passenger arrivals. Peak-hour traffic volumes can be determined by counting the numbers of vehicles on the roadway by type of vehicle (for curbside surveys), recording the number of vehicles on the roadway during each 15-minute increment, and then either identifying the four consecutive 15-minute increments with the largest traffic volumes or the busiest 15-minute increment. It is suggested that surveys of the departures area (passenger drop-off area) roadways be conducted during the 3 hours prior to and including the 60-minute period with the most departing flights, and that surveys of the arrivals area (passenger pickup area) roadways be conducted during the 3 hours including and after the 60-minute period with the most arriving flights. The 60-minute departures and arrivals flight peaks do not necessarily coincide.

Surveys of Traffic Characteristics and Operational Patterns

In addition to surveys of traffic volumes, analyses of airport roadway operations frequently require other surveys to determine the following:

- **Vehicle mix.** In an airport environment, vehicle mix (or vehicle classification) refers to the portion of the traffic volume accounted for by individual modes, as defined by both the type of service each mode provides (e.g., taxicab, courtesy vehicle, charter bus) and the type of vehicle used (e.g., sedan, passenger van, minibus, full-size bus). These data are required to analyze curbside roadway operations.
- **Dwell time.** This is the amount of time a vehicle spends parked at a curbside lane (or other passenger loading or unloading area). Typically, the dwell time is the length of time between when the driver parks (i.e., the vehicle comes to a complete stop) and when the driver first attempts to rejoin the traffic stream (it does not include any time during which the driver may be ready to depart, but is prevented from doing so by other vehicles). For some analyses, it is also helpful to measure "active" dwell times (i.e., the length of time a vehicle remains at a curbside while actively loading/unloading passengers and their baggage) as opposed to the "total" dwell time, which reflects the time difference between when a vehicle first stops at a curbside until it leaves the curbside. Dwell time data are required to analyze curbside roadway operations.
- **Queue length.** Queue length is the distance, time, or number of vehicles in a line of vehicles waiting to proceed along a roadway in which (1) the flow rate of the front of the queue determines the average speed within the queue and (2) the rate of vehicles arriving in the queue is greater than the rate of vehicles leaving the queue. Queues form when a group of vehicles is delayed because of downstream congestion or bottlenecks. The length of a queue can be measured by observing, at fixed intervals, the length of slow moving or stopped vehicles, and the time of a queue can be measured by observing how long it takes a vehicle to travel from the back to the front of a queue. The number of vehicles in a queue and the duration, or persistence, of the queue also can be determined through observations. These data are used to support evaluations of airport roadway operations.
- **Travel speeds.** Average travel speeds can be measured by recording the time it takes random vehicles to travel a known distance, such as between two fixed objects or points. Average travel speeds—particularly along a roadway segment having a length of 1,000 feet or more—can be used to support evaluations of airport roadway operations. Measuring instantaneous speeds (also known as spot speeds) is not useful in airport roadway analyses because the speeds of individual vehicles tend to vary significantly on the roadway network.
- **Other data.** In addition to the data listed above, depending on the nature of the traffic operations problem being addressed, data on vehicle mix (i.e., the proportion of private vehicles, taxicabs, limousines, vans, buses, etc., using the roadways), recirculation volumes (i.e., the proportion of vehicles passing the curbside or other location multiple times, typically determined by recording and matching the license plate numbers of passing vehicles), and curbside occupancies (observations or video recordings of curbside use patterns) are sometimes gathered as part of airport roadway operations analyses. Surveys of airline passengers and visitors are commonly used to gather such data as vehicle mode-choice patterns, passenger arrival patterns, passenger regional approach/departure routes, place of origin/destination, and use of airport parking facilities.

Estimating Future Airport Roadway Traffic Volumes—Traditional Four-Step Approach

Developing a comprehensive estimate of future traffic volumes on airport roadways using the traditional four-step approach involves the following:

- **Trip generation.** Estimating the traffic volume generated by each on-airport land use during the future airportwide peak hour(s) as well as the peak hour(s) of activity for each land use.
- **Trip distribution.** Determining the points where trips generated by each airport land use enter the airport roadway network.
- **Mode-choice analysis.** Analyzing the travel mode choice patterns of passengers and employees.
- **Trip assignment.** Assigning the estimated traffic volumes to the on-airport and regional roadway networks.

In regional planning, the third step—mode-choice analysis—is conducted using sophisticated travel demand forecasting models. These models are used to estimate future mode-choice patterns or changes in existing patterns caused by the introduction of new travel modes (e.g., rail service) or changes in travel time or travel cost. Such models are rarely required in an airport setting. It would be appropriate to include mode-choice analysis during the analyses of airport roadways if a significant change in the existing travel modes were anticipated (e.g., new scheduled public bus or rail service or expansion of existing service) and if this service were expected to attract significant numbers of airline passengers or employees who currently travel by private vehicles.

The three steps applicable to airport roadway operations, as well as challenges to using this approach, are described below.

Estimating Traffic Volumes (Trip Generation)

The key generators of airport roadway traffic are airline passengers and accompanying visitors, employees working at the airport, air cargo and airmail services, airlines, in-terminal concessionaires, and other building tenants plus airport tenants with service or delivery needs. At most airports, the data required to estimate the volume of traffic generated by airline passengers are more readily available than comparable data for employees, air cargo, or service and delivery vehicles.

Reliable statistics on existing monthly and annual volumes of airline passengers and air cargo tonnage and forecasts of airline passengers and air cargo tonnage are available for all commercial-service airports. However, as described in greater detail in subsequent paragraphs, most airport operators have limited-to-no data available on the number of employees working at their airports, or the types of air cargo shipments (e.g., overnight deliveries, small parcels, international, or other types of freight). As a result, forecasts of traffic generated by airline passengers are often developed in substantially more detail than forecasts of traffic generated by employees, air cargo, or services and deliveries. However, traffic generated by airline passengers may represent less than half of the total (daily) vehicular traffic generated at an airport.

Traffic Generated by Airline Passengers

Estimating the volume of traffic generated by airline passengers requires the following inputs.

Number of originating and terminating airline passengers. Roadway traffic operations are analyzed considering the peak-hour volume (i.e., the traffic volume occurring during the busiest 60 consecutive minutes). Analyses of airport roadway traffic begin with the hourly numbers of originating and terminating airline passengers (or preferably the numbers occurring in 15-minute increments). Originating and terminating airline passenger numbers (rather than enplaned and deplaned passenger numbers) are used to generate traffic volumes because these volumes exclude those passengers transferring between flights.

Analyses of hour-by-hour airline passenger numbers indicate when the largest numbers of originating passengers, terminating passengers, and total passengers (originating plus terminating) arrive at, or depart from, the airport. Separate analyses of these three peak periods (originating, terminating, and total) are required because peak periods of demand on some roadway segments coincide with the originating passenger peak periods (e.g., the departures curbside area), and some coincide with the terminating passenger peak periods (e.g., the arrivals curbside area). The total peak period traffic volume may not coincide with the peak period of either the originating or terminating passengers, but may instead reflect the busiest overall period at the airport (e.g., the hour with the largest traffic volumes on the airport entry and exit roadways).

At airports with significant numbers of connecting passengers, the peak hours of airline passenger activity may not correlate with the peak hour of roadway traffic volumes. For airports with multiple terminals or multiple large concourses, it may be necessary to gather these hourly data for each terminal or each concourse.

Existing originating and terminating airline passenger numbers are available through the Origin-Destination Survey of Airline Passenger Traffic, Domestic, an online database published by the FAA, which is based on a 10% sample of all airline tickets collected by U.S. airlines. Since foreign flag airlines are not required to participate in this ticket sample, the published originating-terminating airline passenger data may underreport passenger numbers at major international gateway airports.

Future peak-hour airline passenger numbers are a function of the future flight schedules of each airline, the anticipated size of aircraft operated (i.e., number of seats), and anticipated passenger load factors. Forecasts of airline passengers can be obtained from recent airport master plans, the FAA Terminal Area Forecast (TAF) (see http://aspm.faa.gov/main/taf.asp), and other sources. Master plans may present forecasts of annual or daily airline passenger numbers, as determined using an average day of the peak month or standard busy day rate. Such forecasts may be based on the assumption (particularly at small and medium commercial-service airports) that the existing relationship between peak hour and daily airline passenger numbers will remain constant through the forecast period unless a significant change in airline operations is expected.

Passenger characteristics. When possible, it is helpful to disaggregate the numbers of originating and terminating airline passengers by trip purpose and place of residency rather than just considering the total passenger numbers because airline passenger travel patterns (e.g., vehicle occupancies, circulation, and mode-choice patterns) are a function of their trip purpose (business vs. nonbusiness), place of residence (local residents vs. nonresidents), and type of flight (short-haul domestic, long-haul, transborder, overseas, or other). Typically, these data are obtained from surveys of airline passengers or from data at peer airports. For example, resident travelers are more likely to use private vehicles and park for the duration of their trips, while nonresidents are more likely to travel to the airport in rental cars or hotel/motel courtesy vehicles and not use parking facilities.

Lead and lag times. Airline passenger numbers are reported by the airlines according to the time aircraft are scheduled to depart (push away from the gate), and arrive (touch down). Since these times do not coincide with the times motorists enter and exit airport roadways, to analyze airport roadway traffic operations it is necessary to adjust these times to reflect how much time passengers arrive at the airport in advance of their scheduled flight departure times (lead time) and depart from the airport after their scheduled flight arrival times (lag time). International passengers typically have longer lead and lag times than domestic passengers (because of the 2-hour advance check-in required by most airlines and time required for immigration and customs processing), and leisure travelers typically have longer lead and lag times than business travelers (because they are more likely to have checked baggage). Typically, these data are obtained from surveys of airline passengers or from data at peer airports. Lead time data may be aggregated to form a representative distribution (sometimes referred to as an earliness distribution). Similarly, a representative distribution of lag times is sometimes referred to as a lateness distribution.

Travel mode choices. To convert person trips into vehicle trips, it is necessary to first determine the travel modes used by airline passengers (or the percentage of passengers using each available travel mode). Regional transportation planning often considers just two travel modes—private vehicles and public transit—whereas airport roadway planning requires consideration of taxicabs, limousines, courtesy vehicles, rental cars, scheduled buses, and other travel modes.

As noted, travel modes are a function of trip purpose and place of residency. Airports serving a large proportion of leisure passengers have distinctly different travel-mode-choice patterns than those serving business markets. However, at most U.S. airports, 70% to 80% of all airline passengers arrive and depart in private vehicles or rental cars. Typically, fewer than 5% to 10% of all passengers use public transportation (e.g., scheduled buses or trains, or door-to-door shared ride vans). The remaining passengers typically use taxicabs, courtesy vehicles serving hotels/motels, parking facilities, rental cars, or transportation services that require prior reservations (e.g., limousines, charter or tour buses/vans). Table 3-1 presents the

Table 3-1. Typical vehicle mode choice and occupancies at selected airports—originating airline passengers.

	Los Angeles (*a*)	San Diego (*b*)	Tampa (*c*)	Salt Lake City (*d*)	Typical vehicle occupancy (number of people)
Private Vehicles					
Curbside	42.4%	25.5%	36.3%	27.0%	1.2
Short-term parking	4.4	17.0		8.5	1.3
Long-term parking	8.3	2.5	19.5	7.0	1.3
Off-airport parking (*e*)		10.0		4.5	1.3
Subtotal (private vehicles)	54.8%	55.0%	55.9%	47.0%	
Rental cars	11.4	19.1	36.9	35.0	1.4
Subtotal	66.2%	74.1%	92.8%	82.0%	
Commercial Vehicles					
Taxicabs	9.3%	7.3%	2.3%	1.5%	1.5
Limousines	2.0	1.3	--	2.0	1.5
Door-to-door shuttles	10.0	9.5	3.3	2.0	4.0
Hotel/motel courtesy vehicles	5.1	5.8		10.5	2.6
Public transit	4.1	1.0	0.3	0.5	5.0
Charter/other bus	3.0	1.0	1.4	1.5	15.0
Subtotal (commercial vehicles)	33.5%	25.9%	7.3%	18.0%	
Total	100.0%	100.0%	100.0%	100.0%	

(*a*) Applied Management and Planning Group, *2006 Air Passenger Survey: Final Report. Los Angeles International Airport*, December 2007

(*b*) Jacobs Consultancy, *Interim Report 1: San Diego County Regional Airport Authority. Destination Lindbergh,* December 2008.

(*c*) http://www.tampaairport.com/ground_transportation/transit_survey_presentation.pdf.

(*d*) HNTB, *Landside Report*, *Salt Lake City International Airport*, December 2002.

(*e*) Passengers typically arrive at the curbside in courtesy vehicles.

Source: LeighFisher, July 2009, based on the documents noted above.

mode-choice patterns for typical large-hub airports. These data were obtained from recent studies prepared for Los Angeles, Salt Lake City, San Diego, and Tampa International Airports. Using the format shown in Table 3-1, some airline passengers are counted twice (e.g., a private vehicle driver who parks in an economy lot and rides a courtesy vehicle or a rental car customer who also uses a courtesy vehicle).

Vehicle occupancies. Vehicle occupancies (the number of passengers per vehicle) are used to translate or convert "person trips" by travel mode into vehicle trips. When analyzing airport roadways, vehicle occupancies represent the number of airline passengers in each vehicle (i.e., excluding visitors accompanying airline passengers or the drivers of commercial vehicles). Typically, these data are obtained from surveys of airline passengers (for single-occupancy vehicles, such as private vehicles, taxicabs, and limousines) or from visual observations for multiparty vehicles, such as courtesy vehicles, buses, and vans.

The average occupancy of private vehicles operating on airports is higher than the average occupancy of private vehicles operating on public streets (particularly during commute hours) because vehicles on airports are typically transporting a group of airline passengers rather than just a single occupant.

On-airport traffic circulation patterns. The locations on an airport where motorists begin or end their trips and the paths they follow vary according to their choice of travel mode (and parking facilities), and the on-airport roadway network configuration. Airline passengers follow numerous travel paths on an airport. For example, a private vehicle driver may enter an airport and then do one or more of the following:

- Go directly to the enplaning (or deplaning) curbside area and then immediately exit the airport (e.g., a motorist dropping off an airline passenger who does not park), or recirculate and return to the curbside (e.g., a motorist attempting to pick up a passenger and who was not allowed to remain stopped at the curbside).
- Go first to a cell phone waiting area then proceed to the deplaning curbside to pick up an arriving airline passenger and then immediately exit the airport.
- Go directly to a parking facility and park for the trip's duration (e.g., a long-term parking patron).
- Go directly to the curbside area, drop off passenger(s), and then continue to a parking facility and park for the trip's duration (e.g., a long-term parking patron).
- Go directly to a parking facility, accompany a passenger into the terminal (or greet an arriving passenger at the baggage claim area), and then exit the airport (e.g., a short-term parking patron).
- After landing at the airport, a passenger could go directly to a parking facility, retrieve his/her vehicle (which has been parked for the trip duration), drive back to the terminal to pick up passengers, and then exit the airport (e.g., a long-term parking patron).

Similarly, rental car customers may go to the curbside area before they drop off rental cars or after they pick up rental cars. Commercial vehicle drivers may drop off customers, wait in a holding area, and then recirculate back to the terminal to pick up additional customers. Table 3-2 presents the travel paths and proportion of airline passengers using these paths for a typical large-hub airport. Medium- and small-hub airports have similar patterns, but at these airports there may be greater use of private vehicles and less use of taxicabs, limousines, courtesy vehicles, and public transit vehicles. Again, these data are typically obtained from surveys of airline passengers.

Peak-hour factors. Airport roadway traffic is not uniformly distributed over a typical peak hour or other peak period. At small airports in particular, much larger volumes of traffic may occur during one 15-minute period than during the preceding or subsequent 15-minute period. Peak-hour (adjustment) factors are used to translate nonuniform flows into equivalent hourly flows to allow for the analyses of roadways exhibiting such nonuniform peaks. (This translation is required because roadway capacities are defined and analyses of roadway operations are performed using vehicle volume per hour.) These peak-hour factors can be determined from airport roadway traffic surveys or indirectly from analyses of airline schedules. Traffic volumes generated by airline passengers can be estimated by the following:

- Multiplying the number of originating (or terminating) airline passengers during the peak 60-minute period times the percentage of passengers selecting each travel mode, adjusted using lead (or lag) times, and
- Dividing each volume by the corresponding vehicle occupancy, taking care not to double count the same passengers (e.g., those in courtesy vehicles transporting parking patrons). Exceptions are required for vehicles that may operate on a scheduled basis rather than in direct response to passenger demand (e.g., courtesy vehicles and scheduled buses).

Regression equations that correlate vehicle trips generated to airline passengers to acres of airport property or other measures are provided in *Intermodal Ground Access to Airports: A Planning Guide,* the ITE *Trip Generation Handbook,* and other reference documents. Traffic volume estimates at commercial-service airports developed using such equations are not considered reliable because of the significant differences in the characteristics of each airport, including differences in airline activity peaking patterns and volumes; airline passenger demographics (e.g., trip purpose, place of residency, travel mode

Table 3-2. Typical vehicle circulation patterns—originating airline passengers.

Travel mode	Circulation pattern	Percentage
Private vehicles		
	Drop off at curb, then exit	31%
	Drop off at curb, then park—Hourly, remain	9
	Drop off at curb, then park—Hourly, then exit	4
	Drop off at curb, then park—Daily Parking	7
	Drop off at curb, then park—Economy Parking	4
	Direct to park—Hourly, remain for duration	4
	Direct to park—Hourly, exit immediately	14
	Direct to park—Daily	14
	Direct to park—Economy	9
	Direct to off-airport	4
		100%
Rental Cars		
	Direct to rental car return	73%
	Drop off at curb, then rental car return	23
	Direct to off-airport	4
		100%
Taxicabs		
	Drop off, then exit	83%
	Drop off, then hold area	17
		100%

Source: LeighFisher, July 2009, based on data gathered at Los Angeles International, Salt Lake City International, Tampa International, and other airports.

preferences); passenger circulation patterns on and off the airport; airport layouts; the availability of parking, public transit, and commercial ground transportation services; and other factors influencing traffic volumes.

Traffic Generated by Visitors

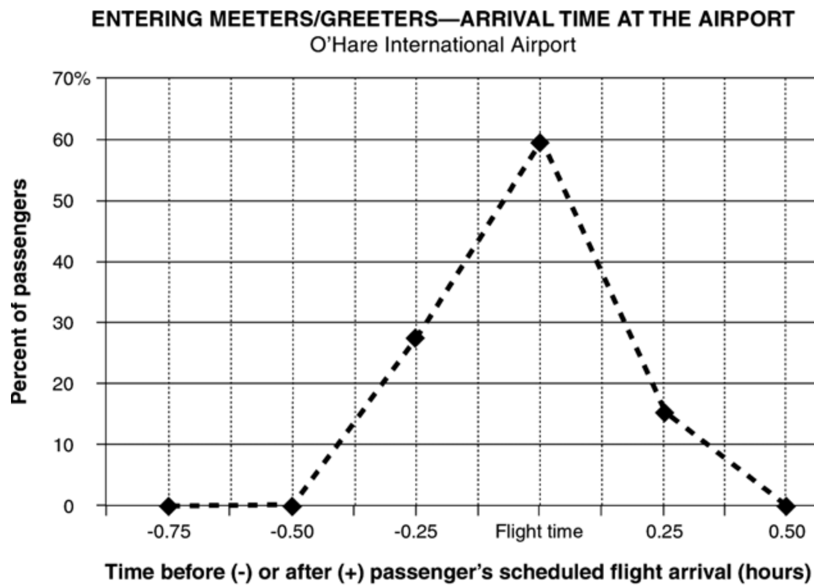
The volume of traffic generated by visitors accompanying departing airline passengers (i.e., well-wishers) and arriving airline passengers (i.e., meeters and greeters) can be determined by establishing the average number of visitors accompanying each airline passenger or group of airline passengers. The number of visitors accompanying a passenger is a function of airline passenger trip destination/purpose and the demographics of the local community. For example, a greater number of visitors is expected to accompany airline passengers traveling overseas for leisure purposes than those accompanying business passengers traveling on domestic flights. In some cities, passengers are greeted by a large extended family group, rather than one or two persons. Typically, visitors either (1) use only the curbside areas, (2) park (for a short period) while they accompany the airline passenger group to/from the terminal building, (3) park (for a short period) in a parking lot (or cell phone lot) and, having met the passenger in the terminal building, return to their vehicle, drive to the curbside area to pick up the passenger, and then exit the airport, or (4) drop off passengers, park, and then return to the terminal to accompany the passengers to/from the gate (e.g., a passenger with special needs, such as an unaccompanied minor or a disabled passenger). The latter pattern (drop off and then park) has become less prevalent since 2001, because visitors are prohibited from accompanying an enplaning passenger to an aircraft gate or greeting a deplaning passenger at a gate.

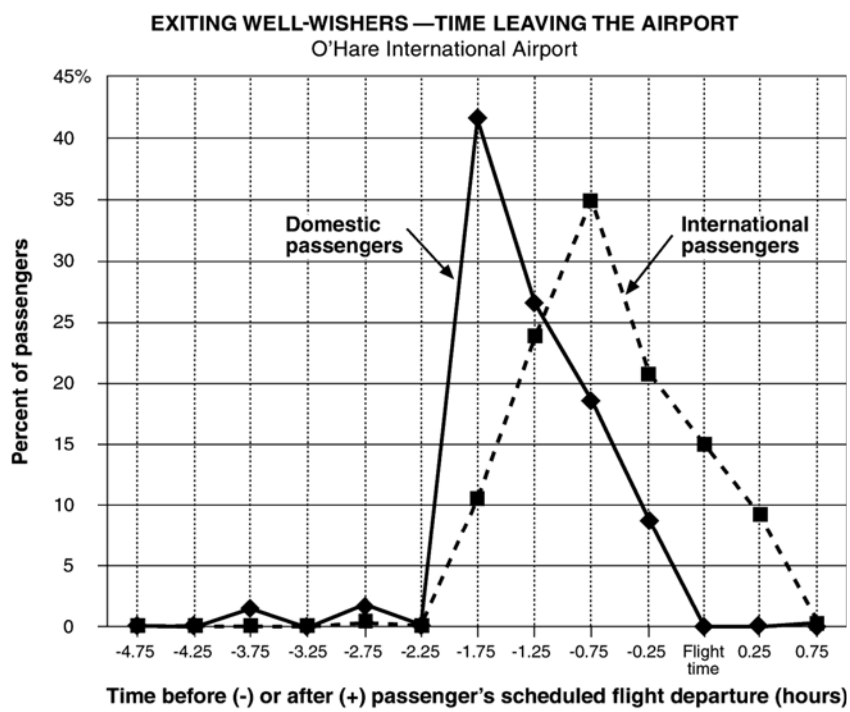
Similar to the travel times for airline passengers, visitor travel times shift from the scheduled aircraft departure and arrival times. (See Figure 3-1.) By far, most visitors travel to and from an airport in private vehicles. They rarely (i.e., less than 5%) use public transportation or other travel modes.

Traffic Generated by Employees

Estimating the volume of traffic generated by airport employees requires the following inputs.

Volume of employees and their work schedules. On an average day, more than 10,000 people work at many large-hub airports and more than 1,000 people work at typical medium-





Source: Kimley-Horn Associates, November 2004, based on analysis prepared for O'Hare Modernization Program Environmental Impact Statement

Figure 3-1. Sample airport visitor lead and lag time.

hub airports (see Table 3-3). These people are employed by the numerous employers located on an airport, as follows:

- The airport operator, including third-party contractors working for the airport operator or sponsor, if different (e.g., janitorial, parking operators, and bus operators), providing services that have been outsourced;
- The airlines, including flight crew, aircraft maintenance, and other employees who may not be working in the terminal building;
- Concessionaires and other terminal building tenants, such as rental car companies and the operators of newsstands, restaurants, and other retail establishments;
- Government agencies, including (at U.S. airports) the FAA, TSA, Customs and Border Protection, Immigration and Customs Enforcement, U.S. Postal Service, and (at some airports) the military;
- Air cargo shippers and forwarders;
- Fixed-base operators; and
- Construction contractors, including construction workers and subcontractors.

Airport-based employees, particularly those employed by the airlines and cargo handlers, work unusual hours, because all commercial airports operate 365 days per year, and many operate 24 hours per day. Typically, the arrival and departure hours of employees at an airport do not coincide with regional commute hours or with an airport's peak enplaning or deplaning hours. For instance, major shift changes for airline employees often occur between 5 A.M. and 6 A.M. and between 2 P.M. and 3 P.M. Another complicating factor is the presence of flight crews, who may only travel to/from the airport a few days per month. The trips made by flight crews at an origin-destination (O&D) airport are sporadic, but while on an assignment, they become like passengers at destination airports—requiring courtesy vehicle service or flight crew transportation services (i.e., chartered vans).

Generally, employers are required to report the total number of their employees requiring security badges, but do not report the number of employees working on each shift, the starting/ending times of each shift, or the travel modes used by their employees. Other than at airports with transportation management programs or ride-share promotional programs, few airport operators have accurate data indicating the number of individuals working at the airport at any given time of day or the travel modes used by these individuals.

Surveys of the employers located on an airport are necessary to determine the number of people working on the airport, their work schedules, travel modes, and circulation patterns. Without such data (or traffic surveys conducted at

Table 3-3. Number of employees at selected airports.

Airport	Hub size	Total employees (*a*)	Parking permits	Estimated average daily employees (*b*)
Boston-Logan International	Large	--	--	14,600
Bush Intercontinental/Houston	Large	--	--	14,406
Chicago O'Hare International	Large	--	--	40,000
Dallas/Fort Worth International	Large	28,654	--	--
Denver International	Large	--	--	17,400
Fort Lauderdale-Hollywood International	Large	14,000	--	4,700
John F. Kennedy International	Large	20,000	7,920	--
Lambert-St. Louis International	Large	--	--	19,000
Las Vegas McCarran International	Large	--	--	8,000
Los Angeles International	Large	--	--	40,000
Phoenix Sky Harbor International	Large	22,000	16,019	8,000
Salt Lake City International	Large	--	--	13,026
San Diego International	Large	--	--	3,000
San Francisco International	Large	12,500	--	--
Seattle-Tacoma International	Large	--	--	11,375
Tampa International	Large	6,000	--	--
John Wayne (Orange County, CA)	Medium	--	--	1,000
Mineta San Jose International	Medium	4,750	--	--
Oakland International	Medium	--	--	10,500
Omaha Eppley Airfield	Medium	--	--	2,500
Portland International	Medium	14,500	--	5,000
Sacramento International	Medium	--	--	1,500

(*a*) Includes badged and unbadged.
(*b*) Number of people working at the airport on an average day.
Source: LeighFisher, based upon information provided by individual airport operators.

the entry/exit to employee parking lots), it is difficult to determine the number and pattern of employee vehicle trips.

Employee travel mode choices. As noted, little data are available describing the travel modes used by employees on an airport. Data presented in *ACRP Report 4: Ground Access to Major Airports by Public Transportation* (2008), indicate that, at 14 airports for which data were available, about 98% of all employees working on the airport arrive and depart in private vehicles (with the exception of Boston-Logan, Chicago O'Hare, and Denver International Airports).

Employee reliance on private vehicles is a result of (1) employees working nontraditional hours that do not coincide with the operations or the schedules of public transportation, (2) employees residing in locations not well served by public transportation (i.e., outside the central business district), (3) employees working in locations outside of the terminal area that are not well served by public transportation, and (4) the availability of free or very-low-cost employee parking on airport property.

One indicator of the number of vehicles driven by employees on an airport is the number of parking permits or identification badges issued by the airport operator to these individuals. For example, in 1996, it was determined that 61% of the employees who were issued security badges at Los Angeles International Airport had also been issued parking permits. The surveys indicated that, on a typical day, 29% of all employees were absent due to staff schedules, vacation, illness, or working away from the office. Of those employees traveling to work on a typical day, it was determined that 64% drove alone, 33% participated in a ride-share program, and 3% rode public transit, biked, or walked. The average vehicle occupancy for those individuals traveling to work at Los Angeles International was 1.38 employees per vehicle. Because most of the large employers operate multiple shifts, about 25% of the daily employee-generated vehicle trips occurred during a single hour. These data are similar to those reported at Boston-Logan International Airport, where about 40% of all employees are absent on a given weekday and about 25% of those working on a given day arrive between 6 A.M. and 10 A.M.

Employee circulation patterns. The use of regional access roads and airport access roads by on-airport employees can be estimated by determining the minimum time path or minimum cost path between their places of residence and place of employment. Place of residence data, summarized at a zip-code level, can be obtained from parking permit applications or from databases of airport-issued security badges. The minimum travel routes between these locations and points of access to the airport can be determined using regional planning models or by planners familiar with the regional highway network.

Future employment and employee work schedules. Forecasts of employment and employee trips tend to be imprecise because reliable estimates of future employment generally are not available and changes in future employment do not correlate well with changes in airline passenger numbers. Historically, planners have estimated future employment assuming that the rate of growth in employment represents the average of the rate of growth in airline passenger and aircraft operations numbers. However, anecdotal information suggests that this assumption is no longer correct because the airlines appear to be reducing their numbers of employees in order to improve productivity levels and reduce costs. For example, the increasing share of passengers who obtain their boarding passes via the Internet or check their bags using electronic ticketing kiosks has reduced the need for ticket counter agents.

It is suggested that additional research is required to develop methods for estimating the volume of traffic generated by employees on airports.

Sample results. Using the steps presented above, the employee trip generation rates presented in Table 3-4 were developed as part of the Los Angeles International Airport Master Plan Update. These data are presented as an example of how employee trip generation rates can vary for a day or over specific hours, and this example is not intended as a suggested proxy for another application.

Traffic Generated by Air Cargo

Air cargo (including airmail) traffic includes the trucks transporting the cargo, the private vehicles driven by the employees in the air cargo terminals, and customer trips. This traffic is generated by air cargo facilities (cargo terminals) located away from the passenger terminal area, freight consolidators or forwarders, and small package deliveries made directly to the terminal area.

It is recommended that the volumes of trips generated by trucks, delivery vans, and air cargo employees be estimated separately. Employee vehicle trips are the largest component of the traffic generated by an air cargo facility (over 70% of the total traffic volume, according to surveys conducted at Memphis and Los Angeles International Airports and other locations).

The volumes of truck and delivery van trips generated by an air cargo facility (i.e., the trip generation rate) are unique to an individual airport and not transferable to other airports. The two measures (or dependent variables) related to air cargo that are most readily available—air cargo tonnage and the size of air cargo buildings—are not reliable indicators of the volume of cargo-related truck or total vehicle trips, largely because there are many different forms of air cargo service,

Table 3-4. Example of vehicle trips per employee working at Los Angeles International Airport.

	Employee trip generation rate (vehicle trips per employee)			
	Daily	Morning peak (8 A.M. to 9 A.M.)	Airport peak (11 A.M. to 12 P.M.)	Afternoon peak (5 P.M. to 6 P.M.)
Inbound	0.59	0.15	0.03	0.01
Outbound	0.59	0.01	0.03	0.15

Source: Leigh Fisher Associates, January 1996, using Los Angeles World Airports' ride-share database representing a typical weekday, Los Angeles International Airport Master Plan—Phase I, On-Airport Existing Transportation Conditions.

including integrated cargo handlers, all-cargo or heavy freight carriers, as well as import, export, and shipments that require special handling (e.g., flowers or fresh fish). Each form of air cargo may generate a different number of truck trips, operate at different truck arrival/departure times, and use different vehicle sizes.

For example, a local overnight delivery service operation might have multiple tractor-trailers picking up and dropping off containers, as well as dozens of local single-unit delivery vehicles distributing packages locally. Conversely, a large import/export freight operation may only generate a few tractor-trailer trips. Thus, although airport operators have reliable statistics on air cargo tonnage transported, tonnage is not a reliable indicator of the volume of truck trips because the volume of trips is a function of the type of cargo service and freight activity, not cargo tonnage (or the size of the air cargo terminal).

Sample results. Although not considered applicable to all airports, the data in Table 3-5, developed for Los Angeles International Airport, present the estimated vehicle trips generated by different cargo facilities (including employee trips) per ton of air cargo.

Data from Chicago O'Hare International Airport, circa 2004, indicate that a general-purpose cargo facility generated about 0.13 daily truck trips per 1,000 annual cargo tons.

As noted, air cargo is transported by a wide variety of cargo shippers, each having different trip generation rates. Little, if any, research has been published, or documented, on air cargo trip generation. Additional research is required to develop methods for estimating the volume of traffic generated by air cargo terminals at airports and the employees working in these terminals.

Traffic Generated by Service and Delivery Vehicles

Service and delivery vehicles include those vehicles (1) bringing goods and materials (other than air cargo) to/from terminal building loading docks, consolidated warehouses, and other sites on an airport, (2) transporting individuals performing airport maintenance and construction, (3) being used by airport police, fire, and emergency response staff, and (4) making trips not directly generated by airport passengers, employees, or air cargo. At most airports, little to no data are available on the current volume of service, delivery vehicle trips, or the activities generating these trips (i.e., the extent of goods and material deliveries, trash removal, emergency responses, or construction deliveries and traffic).

Generally, no data are available to guide estimates of the future volume of service/delivery vehicle trips, or the extent of future activities generating these trips. Additional research is required on this topic.

Table 3-5. Estimated airport cargo trips per daily cargo tonnage at Los Angeles International Airport.

		Facility peak hour				Commuter peak hour			
		Morning		Afternoon		Morning		Afternoon	
Cargo shipper	Daily trips (in and out)	In	Out	In	Out	In	Out	In	Out
International airline	25.2	0.39	0.13	0.19	0.29	0.23	0.13	0.16	0.16
Domestic airline	6.9	0.21	0.20	0.30	0.18	0.17	0.08	0.17	0.13
Overnight delivery service	3.0	0.30	0.24	0.77	0.27	0.30	0.03	0.55	0.26

Source: Leigh Fisher Associates, January 1996. Los Angeles International Airport Master Plan—Phase I, On-Airport Existing Transportation Conditions.

Traffic Generated by Other Airport Land Uses

Other land uses commonly found at public airports include general aviation/FBO facilities and military bases. At most commercial-service airports, these other land uses do not generate significant volumes of traffic during the peak hours for the airport or regional highway network. When the analysis is focused on the airport terminal area and primary airport access roadways, the traffic volumes generated by these land uses are often ignored or considered to be "background" traffic and combined with that of service/delivery vehicles.

Traffic volumes generated by general aviation are a function of the number of general aviation aircraft operations, and the type of aircraft (business jets, air taxis, or small propeller aircraft). Traffic volumes generated by military bases vary according to the type of base and its function. Traffic volumes generated by nonaviation land uses that are not related to airport or aviation activity (e.g., industrial parks or large retail centers) can be estimated using the ITE *Trip Generation Manual.*

Traffic Generated by Nonairport Vehicles Using Airport Roadways

Vehicles not related to the airport or airport land uses may use airport roadways as a shortcut to bypass congestion or delays on the regional roadway network. This traffic, commonly referred to as cut-through traffic, adds to airport roadway requirements and contributes to airport roadway congestion. Cut-through traffic occurs at airports having multiple entrance and exit points (e.g., Dallas/Fort Worth, Phoenix Sky Harbor, and Washington Dulles International Airports, and Bush Intercontinental Airport/Houston) and where the roadway network configuration allows nonairport traffic to share the airport roadways with airport-generated traffic. Most airport operators discourage such cut-through traffic.

Determining the volume or proportion of existing cut-through traffic may require recording and matching the license plates or electronic toll tags of vehicles entering and exiting the airport at all major airport entry and exit points (i.e., a license plate matching survey or toll tag survey). It is not possible to identify cut-through traffic volumes using simple traffic volume counts.

Estimating the volume of future cut-through traffic requires an understanding of future regional land uses and expected regional traffic patterns/travel times. The volume of nonairport traffic using airport roadways is a function of the volume of traffic on the regional roadways, and the travel-time savings these vehicles would experience if they were able to use airport roadways as a shortcut. These time savings can be determined by comparing the travel times via airport roadways and on alternative routes, knowing the forecast congestion and travel times on these routes as forecast by regional travel models or other sources.

Off-Airport Origin and Destination Points (Trip Distribution)

Some non-hub and small-hub airports have single entry/exit points. At these airports, all vehicles enter and exit via one roadway. The regional approach and departure vehicle distributions may be required to determine the proportion of left-turn, right-turn, and trough traffic at the intersection of the airport roadway with the regional highway network.

Many airports have multiple entrance/exit points—one serving the terminal area and separate entrances/exits for aircraft maintenance centers, general aviation terminals, military bases, or other land uses. Although the volume of traffic using each entrance/exit can often be determined by the land use(s) served by the specific entrance/exit, large airports may have multiple connections to the regional roadway system, where the use of each is determined by regional travel patterns (or a combination of regional travel patterns and the on-airport destination).

For these large airports with multiple connections to the regional roadway system, it is necessary to know the routes drivers follow when traveling to and from the airport in order to analyze (1) the intersections or junctions of the airport access roadways and regional roadway network, (2) traffic volumes on airport roadways associated with specific connections to the regional roadway network, and (3) the effect of airport traffic on the regional roadway network. The routes drivers follow are a function of where they enter airport property and their on-airport destinations. These locations (or the distribution of these locations) are a function of airline passenger trip purpose, place of residency, regional land use patterns, the regional highway network, existing and forecast roadway congestion/travel times, the availability of public transit, and other factors.

At airports having multiple entry/exit points serving the terminal area (or other major land use), drivers typically select the most convenient entry/exit point, which generally implies the point that minimizes travel time. It is possible to estimate the proportion (and thereby the volume) of vehicles using each entry and exit point by determining (1) the actual locations where motorists (including airline passengers, visitors, and employees) begin their trips to the airport (or end their trips from the airport) or the distribution of these locations, and (2) the most logical routes used by motorists from each of these origin or destination points.

At many airports, fewer than 30% of all trips begin/end in the downtown area, with the remainder arriving from or going to places of residency and employment distributed throughout the region. A planner familiar with the regional highway network can determine the most likely routes from the primary regional origin and destination points. In addition, these data (or trip distributions) can be obtained from surveys of airline passengers or, when such data are not available, from the local metropolitan planning organization, which can provide information on future distributions of places of residence and employment, a description of the future regional transportation network, and the likely travel paths or approach/departure distributions.

Assigning Traffic Volumes to the Roadway Network (Trip Assignment)

Assigning the traffic volumes generated by airline passengers, visitors, employees, air cargo, and service/delivery vehicles to the on-airport roadway network requires information as to (1) where these vehicles enter or exit the airport, (2) their final and interim destination or origination points on the airport, and (3) the routes or paths available to these vehicles.

- **Airport entry and exit points.** The methodology for determining traffic volumes entering and exiting an airport at specific locations is provided earlier in this chapter (see Estimating Traffic Volumes [Trip Generation]).
- **Origin and destination points on the airport.** The methodology for determining the volumes of trips associated with specific on-airport origins and destinations is also provided in the previous section on Estimating Traffic Volumes (Trip Generation).
- **Travel paths.** Typically, on a regional roadway network motorists can select from several alternative travel paths. Thus, a sophisticated traffic assignment procedure is required to allocate these vehicle trips among the available travel paths (i.e., to assign the vehicle trips to the regional roadway network) and, if desired, allocate trips to alternative routes, as primary routes become congested and travel times decrease. In comparison, on an airport, there is generally only a single logical travel path available for airline passengers and visitors, employees, and air cargo vehicles. Thus, the traffic assignment process is much simpler at airports.

At most airports, there is only one travel path available between the airport entry and exit points and the primary origin/destination points. For example, at most airports, there is only one route connecting the airport entrance/exit and the terminal curbside areas, public parking areas, or rental car ready/return areas.

Exceptions include those airports having several entrances/exits used by airline passengers, or having multiple terminal buildings served by separate roadways. Some large airports provide internal bypass roads allowing motorists to avoid slow moving traffic at curbsides or other areas of potential congestion.

Generally, at an airport, most motorists follow the guide signs directing them to the major on-airport destinations. Furthermore, most motorists will follow the prescribed routes even if they become congested, and typically deviate to a different route only if directed to do so by a traffic control officer. Most employees and service vehicle drivers follow the quickest route, unless they are prohibited from using specific roads, or tolls or fees are associated with the use of specific routes.

The travel paths of originating airline passengers can be determined using the information presented in Table 3-1 (revised for the specific characteristics of the airline passengers and airport being analyzed), and the travel paths of terminating airline passengers can be determined using similar information. As noted, care must be taken when assigning trips made by passengers who use multiple travel modes (e.g., those who park in a remote parking lot and also use a courtesy vehicle) or multiple legs (e.g., those who go to the curb and then to parking).

For example, assuming that 100 vehicle trips per hour are generated by originating airline passengers at an airport; 65% of these trips are generated by private vehicles; 30% of those private vehicles go to the curb and then go to parking, where they remain for their trip duration; and 80% arrive from the east and 20% arrive from the west, these assumptions result in 20 vehicle trips by private vehicles using both the curb and daily parking ($100 \times 65\% \times 30\%$), of which 16 vehicles enter from the east and 4 enter from the west.

The trip assignment process for airport roadways requires (1) repeating this calculation for every combination of travel mode, circulation path, and regional approach/departure path, (2) assigning these vehicle trips to the corresponding roadway links, and (3) finally determining the sum of all vehicle trips assigned to each roadway link. The sum of the vehicle trips on each roadway link represents the estimated traffic volume on that link. Travel forecasting software or spreadsheet analyses are frequently used to perform this repetitive process, particularly when traffic forecasts are being prepared for large airport roadway networks. The use of these methods allows planners to readily test the implications of alternative assumptions regarding mode choice, travel paths, or airline passenger activity patterns, as well as saving time and effort.

Challenges with Estimating Roadway Traffic Volumes

As noted, several challenges are associated with estimating roadway traffic volumes—either existing or future—using the traditional four-step travel forecasting techniques. Key challenges encountered by most airport operators include the following.

Lack of Data on Airline Passengers

Most airport operators do not conduct regular surveys of the travel modes used by airline passengers, the occupancies of vehicles transporting airline passengers, their lead and lag times, or their on-airport circulation patterns (e.g., the percent using parking or curbside areas). It is estimated that fewer than 20 U.S. airport operators regularly conduct surveys of the travel modes and circulation patterns of airline passengers and have access to current data.

Lack of Data on Hourly Passenger Volumes

Many airport operators do not have accurate data on hour-by-hour originating/terminating airline passenger numbers. At many airports, for planning purposes, hourly airline passenger numbers are calculated using (1) reported aircraft arrival and departure schedules, (2) aircraft sizes (and corresponding seat capacities) to determine the number of available seats per hour (or other time increment), (3) assumed load factors (by airline)—the portion of seats occupied by passengers, and (4) the assumed portion of originating or terminating passengers (by airline). A minor difference in the estimated load factor or the proportion of enplaned/deplaned passengers in the peak hour can lead to significant differences in the numbers of peak-hour passengers. Furthermore, although planners recognize that aircraft load factors vary throughout the day and by day of the week, typically, a single load factor is applied to all aircraft of a given airline. Similarly, while the percentage of passengers who originate or terminate at an airport may vary significantly throughout the day, typically only a single originating/terminating factor is applied to all passengers of a given airline.

Lack of Data on Airport Employees

As previously noted, most airport operators have little or no data regarding the numbers of employees reporting to work on a daily basis, and less data on the hour-by-hour arrival/departure patterns and travel modes used by these employees. Few, if any, airport operators have forecasts of future employment that are considered to be as reliable as the available forecasts of airline passengers.

Lack of Data on Air Cargo and Service/Delivery Trips

As noted earlier, additional research is required on air cargo and service/delivery vehicle trips. At most airports, little data are available on the existing numbers of trips generated by these land uses and no reliable method exists for forecasting future trips.

Effort Needed to Gather Required Data

Comprehensive surveys of originating and terminating airline passengers can be costly and time consuming to plan, authorize, and conduct, with several months required to review and summarize the resulting data before they are available for release to others.

Resulting Accuracy

As noted, forecasts of the traffic volumes generated by airline passengers are often prepared in substantially more detail than forecasts of traffic generated by employees, air cargo, or service/deliveries. However, although traffic generated by airline passengers may account for over 70% of the traffic during the peak hour, it typically represents less than half of the daily traffic generated by an airport. The costs and time required to gather the airline passenger data needed to forecast airline passenger vehicle trips should be compared with the benefits (i.e., anticipated level of accuracy).

Estimating Future Airport Roadway Traffic Volumes—Alternative Approach

An alternative approach to estimating future airport roadway traffic volumes involves determining existing traffic volumes on each roadway segment (or major segments) and applying a growth factor to the peak-hour volume to represent future conditions. This alternative approach is commonly called the "growth factor method." It is suitable for quick analyses of airport curbside and terminal area roadway operations for planning purposes. Compared to the four-step forecasting approach, this approach can be applied relatively quickly and inexpensively. The growth factor method requires (1) determining the existing peak hour(s) roadway traffic volumes on each roadway segment or major segments, (2) developing growth factors, and then (3) multiplying the existing peak roadway traffic volumes by the selected growth factor to develop an approximation of future conditions.

Growth Factor Method for Estimating Future Traffic Volumes

A growth factor is the ratio between traffic volumes in the current peak hour and in the peak hour to be analyzed. A growth factor can be based on the ratio of the forecast total annual airline passenger numbers (enplaned plus deplaned passengers) for the future year to be analyzed to the equivalent existing airline passenger numbers. Seasonal growth factors can be developed to adjust for peak-month traffic operations using data commonly available at most airports. For example, seasonal factors can be developed using the ratio of parking revenues (or, preferably, public parking transactions) during the peak month to the revenues during the current month or the ratio of month-to-month airline passenger numbers.

Challenges with Use of the Growth Factor Method

The major challenge with using the growth factor method is that it is relativity simplistic. This method is based on the assumption that existing patterns of activity and circulation will remain unchanged throughout the forecast period. This method also may not account for changes that may result from

- New land uses on or near the airport that could affect the paths that motorists follow when entering or exiting the airport.
- Changes in choices of travel modes, parking facilities, or circulation paths that may result from new or improved public transportation services, changes in parking facilities or parking rates, or increases or decreases in the propensity of motorists to use curbside roadways.
- Changes in the proportion of airline passengers during the future peak month, peak day, or peak hour, although these changes could be compensated for by adjusting the growth factor appropriately. For example, if the peak hour is expected to account for a smaller proportion of daily traffic due to anticipated changes in airline schedules or a “flattening” of the peak due to increased traffic volumes, the growth factor could be adjusted accordingly.
- Changes in the roadway network on or near the airport. For example, the construction of a new major regional highway may affect how vehicles approach the airport and turning movement patterns at the airport entry/exit. Similarly, a new or modified airport roadway could alter internal traffic circulation and merging or weaving patterns on the airport.

CHAPTER 4

Analyzing Airport Terminal Area Roadways

This chapter presents an overview of terminal area roadway analyses. It presents level-of-service definitions applicable to airport roadways and describes methods for estimating the capacity and levels of service. Chapter 5 presents comparable methods for analyzing curbside roadways.

As described earlier, a hierarchy of analytical methods—including quick-estimation, macroscopic, and microsimulation methods for analyzing airport terminal area roadway and weaving section operations, is proposed. The appropriate analytical method will evolve as a project proceeds from concept to final design, and as more time and data become available to support the analyses.

This chapter presents the suggested quick-estimation methods for analysis of airport roadways with uninterrupted flows, signalized roadways, and airport roadway weaving sections; the macroscopic method for analyzing low-speed roadway weaving areas commonly found on airports; and an overview of the use of microsimulation methods.

The macroscopic methods and performance measures presented in the 2000 HCM are considered applicable for analyses of airport roadways with uninterrupted traffic flows and unsignalized or signalized intersections, but not for analyses of low-speed roadway weaving areas. It is suggested that the method presented in the section on Macroscopic Method for Analyzing Airport Roadway Weaving Areas be used when macroscopic analyses of airport weaving areas are required, and that the methods presented in the HCM be used for macroscopic analyses of all other airport roadways.

The methods and data presented in this chapter represent the best available information concerning airport roadway operations and the consensus of the research team, the Project Panel, and other reviewers at the time this Guide was prepared. It is suggested that additional research be conducted on low-speed weaving areas and maximum service rates for airport roadways.

Level-of-Service Definitions for Airport Terminal Area Roadways

The key performance measures defining the level of service of an airport terminal area roadway are as follows:

- Average speed, which determines travel time;
- Traffic density, which determines the ability of motorists to easily maneuver into and out of travel lanes;
- Maximum volume-to-capacity (v/c) ratio, which indicates how close the roadway is to breakdown and is useful for determining other performance measures such as queue length and delays; and
- Duration and length of queues.

With the exception of the weaving analysis discussed in this chapter, the definitions, metrics, and procedures presented in the 2000 HCM are applicable to airport roadways with uninterrupted operations and signalized and unsignalized (i.e., stop-sign controlled) intersections.

The weaving analysis methods presented in the 2000 HCM (and the 2010 update) are primarily oriented toward operations on freeways or major arterial streets. At airports, weaving often takes place on roadway segments designed for speeds that are much slower than those on freeways or even on major arterial streets. As a result, although the weaving theory and methods presented in the 2000 HCM (and subsequent updates) are applicable to airport roadways, the metrics defining levels of service are not. Consequently, subsequent portions of this chapter present alternative metrics for the low-speed weaving that occurs on airport roadways.

Quick-Estimation Methods for Analyzing Airport Roadway Operations

This section presents quick-estimation methods for analyzing uninterrupted flows, signalized roadways, and airport roadway weaving sections.

Quick-Estimation Method for Uninterrupted Flows on Airport Roadways

Quick-estimation methods are most appropriate for "sizing" a roadway in the early stages of planning and the design process when little has been decided (or is known) about the details of the required roadway. Such methods are suitable for use when preparing airport master plans or terminal area plans to size or evaluate a roadway and identify points of existing or future constraints.

Table 4-1, which is adapted from Exhibits 21-2 and 21-3 of the 2000 HCM, presents the maximum service flow rate and adjusted flow rates for multilane roadways with uninterrupted flows. The adjusted flow rates represent the maximum flow rates of typical airport access and circulation roadways and were calculated assuming that (1) heavy trucks and buses represent less than 5% of the traffic volume on the access roadways, (2) courtesy vehicles and minibuses (which are assumed to be equivalent to recreational vehicles in terms of performance) represent about 10% of the traffic volume on access roadways, and (3) a high proportion of drivers who are infrequent users of, and are, therefore, unfamiliar with, the airport roadways. The free-flow speeds can be approximated by the posted speed limits on the roadway section unless drivers

Table 4-1. Levels of service for airport terminal area access and circulation roadways.

Criteria	Level of service A	B	C	D	E
	Free-flow speed = 50 mph				
Minimum speed (mph)	50.0	50.0	50.0	48.9	47.5
Maximum volume/capacity ratio	0.28	0.45	0.65	0.86	1.00
Maximum service flow rate (passenger cars/hour/lane)	550	900	1,300	1,710	2,000
Maximum flow (vehicles/hour/lane) (*a*)	440	730	1,050	1,380	1,620
	Free-flow speed = 45 mph				
Minimum speed (mph)	45.0	45.0	45.0	44.4	42.2
Maximum volume/capacity ratio	0.26	0.43	0.62	0.82	1.00
Maximum service flow rate (passenger cars/hour/lane)	490	810	1,170	1,550	1,900
Maximum flow (vehicles/hour/lane) (*a*)	400	650	940	1,250	1,530
	Free-flow speed = 40 mph				
Minimum speed (mph)	40.0	40.0	40.0	39.0	38.0
Maximum volume/capacity ratio	0.26	0.42	0.61	0.82	1.00
Maximum service flow rate (passenger cars/hour/lane)	450	740	1,060	1,400	1,750
Maximum flow (vehicles/hour/lane) (*a*)	360	600	860	1,130	1,410
	Free-flow speed = 35 mph				
Minimum speed (mph)	35.0	35.0	34.0	34.0	33.0
Maximum volume/capacity ratio	0.26	0.42	0.61	0.80	1.00
Maximum service flow rate (passenger cars/hour/lane)	410	670	980	1,280	1,600
Maximum flow (vehicles/hour/lane) (*a*)	330	540	790	1,030	1,290
	Free-flow speed = 30 mph				
Minimum speed (mph)	30.0	30.0	30.0	29.6	29.0
Maximum volume/capacity ratio	0.26	0.41	0.60	0.79	1.00
Maximum service flow rate (passenger cars/hour/lane)	370	600	870	1,150	1,450
Maximum flow (vehicles/hour/lane) (*a*)	300	480	700	930	1,170
	Free-flow speed = 25 mph				
Minimum speed (mph)	25.0	25.0	25.0	24.8	24.0
Maximum volume/capacity ratio	0.25	0.40	0.59	0.79	1.00
Maximum service flow rate (passenger cars/hour/lane)	310	500	740	990	1,250
Maximum flow (vehicles/hour/lane) (*a*)	250	400	600	800	1,010

mph = miles per hour

(*a*) Flow rates adjusted to account for 0.95 heavy vehicle factor and 0.85 driver population factor due to occasional or unfamiliar users.

Source: LeighFisher, based on information presented in Transportation Research Board, National Research Council, *Highway Capacity Manual,* Exhibits 21-2 and 21-3, December 2000.

regularly exceed the posted speed limit, in which case the free-flow speed can be approximated by the average operating speed of the vehicles on the roadway.

These adjusted flow rates also are based on the following assumptions:

- Travel lanes are at least 12 feet wide.
- Lateral clearances (e.g., distance from walls, abutments, or other physical obstacles) are at least 6 feet on both the left and right sides of the roadway.
- Any vertical grades are less than 0.25-mile in length or less than 3% (i.e., rises less than 3 feet per every 100 feet of length).
- The roadways operate in one direction only, or for two-way roadways, at least two travel lanes are provided in each direction, separated by a median.

The 2010 HCM includes tables that can be used to modify travel speeds and flow rates for conditions other than those described above.

If the roadway being evaluated falls significantly outside the lane width, lateral clearance, percent of truck use, and varies from the other factors listed, then the traffic volume thresholds presented in Table 4-1 may not be accurate. A more detailed macroscopic analysis using procedures described in the 2000 HCM (or the 2010 update) may be necessary to determine the maximum service volume for the facility.

If the lane width, lateral clearance, percent of truck use, and other factors described are applicable to the roadway being analyzed, then the information in Table 4-1 should be applied as follows:

1. Determine the free-flow speed for the roadway. The free-flow speed is usually determined by measuring the mean speed of traffic under very light flow conditions. However, the posted speed limit can be used as an approximation of the free-flow speed.
2. Determine the target level of service. The target is determined by individual airport operators (or local agencies) and reflects their individual policies and standards. If such a standard or policy is lacking, LOS D is a common standard for urban roadways, although many urban agencies have adopted LOS E as a standard. LOS C is considered the common standard for planning new airport facilities, although at large-hub airports, LOS D is sometimes considered to be acceptable on existing roadways during peak periods.
3. Using Table 4-1, select the appropriate free-flow speed and the column with the desired level of service. The maximum flow provides the maximum traffic per hour per lane that the roadway can serve in one direction.

   For example, if the free-flow speed is 50 mph and the target level of service is LOS D, then the maximum desirable flow rate for a two-lane one-way road would be 2,760 vehicles per hour (twice 1,380).

Quick-Estimation Method for Signalized Roadways

The 2000 HCM (Appendix A, Chapter 10) presents a quick-estimation method for roadways and signalized intersection operations that is considered applicable for analysis of airport roadways. An alternative quick-estimation method—the planning application of the critical movement analysis or Intersection Capacity Utilization (ICU) method—also is applicable to airport roadways with signalized intersections. The ICU method involves the following steps:

1. Identify the lane geometry.
2. Identify the hourly volumes, including left-turn, through, and right-turn volumes for each intersection approach.
3. Identify the signal phasing (i.e., which movements operate concurrently).
4. Perform left-turn check to determine the probability of each critical approach volume clearing the identified opposing or conflicting left-turn volume.
5. Assign lane volumes.
6. Identify critical volumes by identifying the conflicting or opposing traffic volumes (on a per lane basis) having the highest total volumes for each signal phase.
7. Sum the critical volumes.
8. Determine the intersection level of service.

Appendix F of this Guide presents an explanation of the use of the planning application of the critical movement analysis method and a worksheet to guide users.

Quick-Estimation Method for Airport Roadway Weaving Sections

Table 4-2 provides example data for a procedure for quickly estimating the maximum service volumes on airport roadway weaving sections for one-sided and two-sided weaving areas. These service volumes were developed using the macroscopic method described in the next section.

Macroscopic Method for Analyzing Airport Roadway Weaving Areas

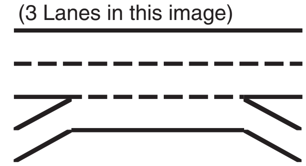
The 2000 HCM and the draft 2010 HCM provide methodologies for evaluating traffic operations on airport roadways. However, neither edition of the HCM is designed to evaluate weaving conditions for low-speed airport roadways (speed limits of 30 mph or slower). In fact, commercially available software for applying the HCM methods generally prohibit the user from applying the software to weaving sections with free-flow speeds lower than 35 mph.

Consequently, a separate weaving analysis without the limitation on low free-flow speeds was developed and incorpo-

Table 4-2. Example service volumes for airport roadway weaving segments.

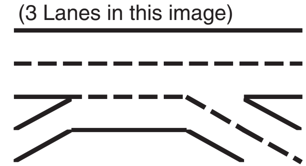
Number of lanes in weaving section	One Sided Ramp Weave (single lane ramp) Service Volumes (vehicles/hour) for LOS				
	A	B	C	D	E
3	1,300	1,800	2,200	2,600	4,200
4	1,650	2,250	2,800	3,200	5,600
5	2,000	2,700	3,300	3,800	6,200

(3 Lanes in this image)



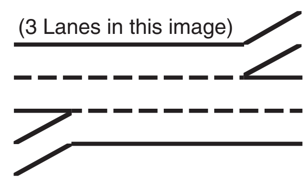
Number of lanes in weaving section	One Sided Ramp Weave (two lane ramp) Service Volumes (vehicles/hour) for LOS				
	A	B	C	D	E
3	1,450	2,100	2,700	3,250	4,200
4	1,950	2,800	3,600	4,300	5,600
5	2,400	3,500	4,450	5,350	6,200

(3 Lanes in this image)



Number of lanes in weaving section	Two Sided Ramp Weave Service Volumes (vehicles/hour) for LOS				
	A	B	C	D	E
3	1,400	1,950	2,500	2,950	4,150
4	1,800	2,500	3,150	3,700	5,550
5	2,150	3,000	3,700	4,300	6,950

(3 Lanes in this image)



Notes:
Table uses arbitrarily selected volume combination with free flow speed of 35 mph, level terrain, weaving segment length of 500 feet, 5% heavy vehicles, and approximately 20% of traffic weaving. This table is an example of what service flows could be for one volume pattern and is not intended to function as a look-up table for a quick estimation method.

rated into a macroscopic model—the Quick Analysis Tool for Airport Roadways (QATAR). QATAR includes components that provide information about low-speed weaving and curbside roadway operations given certain inputs. The low-speed weaving operations are described in this section. The curbside operations components are described in Chapter 5.

QATAR uses the weaving analysis calculations and methodology presented in Chapter 12 of the draft 2010 HCM for one-sided and two-sided weaving, and applies these calculations to roadways having free-flow speeds slower than the lower bound of speeds presented in the draft 2010 HCM (free-flow speeds less than 35 mph).

The draft 2010 HCM weaving methodology is described below so that analysts can follow its implementation within QATAR. Two modifications were made to the draft 2010 HCM weaving method to extend its application to lower speed roadway sections. First, the minimum speed for weaving traffic was reduced from 15 mph in the draft 2010 HCM materials to 10 mph. Second, special LOS threshold traffic densities were developed for application to weaving sections on low-speed airport roadways. As an input in determining the capacity of the weaving segment, maximum service flow rates for basic freeway segments under base conditions were extrapolated to correspond to input free-flow speeds (i.e., less than 55 mph).

The draft 2010 HCM presents macroscopic methods for analyzing airport roadway operations. These methods, if adjusted for the factors used to develop Table 4-1 (e.g., driver population, heavy vehicles, and roadway geometry), are applicable to analysis of airport roadways with uninterrupted traffic flows and flows controlled by signals or stop signs.

Use of Draft 2010 Weaving Analysis Procedures

The draft 2010 HCM weaving analysis procedure involves the following steps, which are described in this section:

1. Collect and input roadway weaving section lane geometry, lane designations, free-flow speed, and peak hour volumes.
2. Adjust the mixed-flow traffic volumes to equivalent passenger car volumes (adjust for percent of heavy vehicles, driver familiarity, and peak-hour factor).

3. Determine configuration characteristic, which is based on lane changes of weaving movements.
4. Determine the maximum weaving length, if weaving analysis is appropriate.
5. Determine the weaving section capacity.
6. Determine lane-changing rates.
7. Determine the average speed of weaving and nonweaving vehicles.
8. Determine the level of service.

The rest of this section describes these steps in more detail with the recommended modifications for applying this analysis to weaving sections of low-speed airport roadways. Additional detail on these steps is provided in the draft 2010 HCM.

Collect and Input Data

The analyst must collect data on existing and/or forecast peak-hour traffic volumes for each leg of the weaving section. The traffic data should include a peak-hour factor and percent of heavy vehicles. The peak-hour factor is the ratio of the total peak-hour flow rate in vehicles per hour (vph) divided by the peak 15-minute flow rate within the peak hour (converted to vph).

The free-flow speed or posted speed limit should be observed (or estimated in the case of a new design or planning study).

The proposed (or existing) lane geometry must be identified (number of lanes on each leg, number of lanes in the weaving section, lane striping showing how the lanes on each leg transition to and from the lanes in the weaving section, and the length of the weaving section).

Adjust Flow Rates

The mixed (passenger cars, trucks, buses, etc.) flow rates should be converted to the equivalent passenger car rates using the following formula:

$$v_i = \frac{V_i}{(PHF)(f_{HV})(f_p)}$$

where

v_i = equivalent passenger car flow rate (passenger cars per hour, or pc/hr)
V_i = the mixed flow rate (vph)
PHF = peak-hour factor
f_{HV} = the heavy vehicle adjustment factor
f_p = driver familiarity adjustment factor

The heavy vehicle adjustment factor is computed as follows:

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$$

where P_T, E_T, P_R, E_R, are percentage and equivalence of trucks/buses and recreational vehicles in the traffic stream, respectively.

The presence of recreational vehicles is typically negligible for airport facilities. Suggested truck equivalence is 1.5 for level terrain, which is typical for airport roadways. A peak-hour factor of 0.9 is suggested in absence of field-collected data. For airport roadways where arriving and departing passengers constitute the predominant users, a value of 0.85 should be used for the driver familiarity adjustment factor (the full range should be between 0.85 and 1.0, with 0.85 representing unfamiliar drivers, and 1.0 representing regular commuters).

The user has two options for entering traffic volumes through the weaving segment. The first option is to enter actual O&D counts (or volumes) on the weaving section, and the second option is to enter approach and departure volumes, and then use QATAR to estimate the weaving volumes in the segment.

Determine Weaving Configuration

Several key parameters characterize the configuration of a weaving segment. The first step is to determine whether the roadway being analyzed is a one-sided ramp weave or a two-sided weave (illustrations are provided in QATAR as well as in Figures 4-1 and 4-2). The key variables in subsequent steps of the methodology for both types of weaving configurations are

LC_{MIN} = minimum rate at which weaving vehicles must change lanes to successfully complete all weaving maneuvers (lc/hr).
N_{WL} = number of lanes from which weaving maneuvers may be made with either one lane change or no lane changes. For one-sided weaving, this value is either 2 or 3, and for two-sided weaving, this value is always 0 by definition.

For a one-sided weaving segment, the two weaving movements are the ramp-to-freeway and freeway-to-ramp flows; the following values are established:

LC_{RF} = minimum number of lane changes that must be made by one ramp-to-freeway vehicle to successfully execute the desired maneuver.
LC_{FR} = minimum number of lane changes that must be made by one freeway-to-ramp vehicle to successfully execute the desired maneuver.
LC_{MIN} = minimum rate of lane changing that must exist for all weaving vehicles to successfully complete their weaving maneuvers, lc/hr
= $(LC_{RF} * v_{RF}) + (LC_{FR} * v_{FR})$.
v_{RF} = ramp-to-freeway demand flow rate in weaving segment, pc/hr.

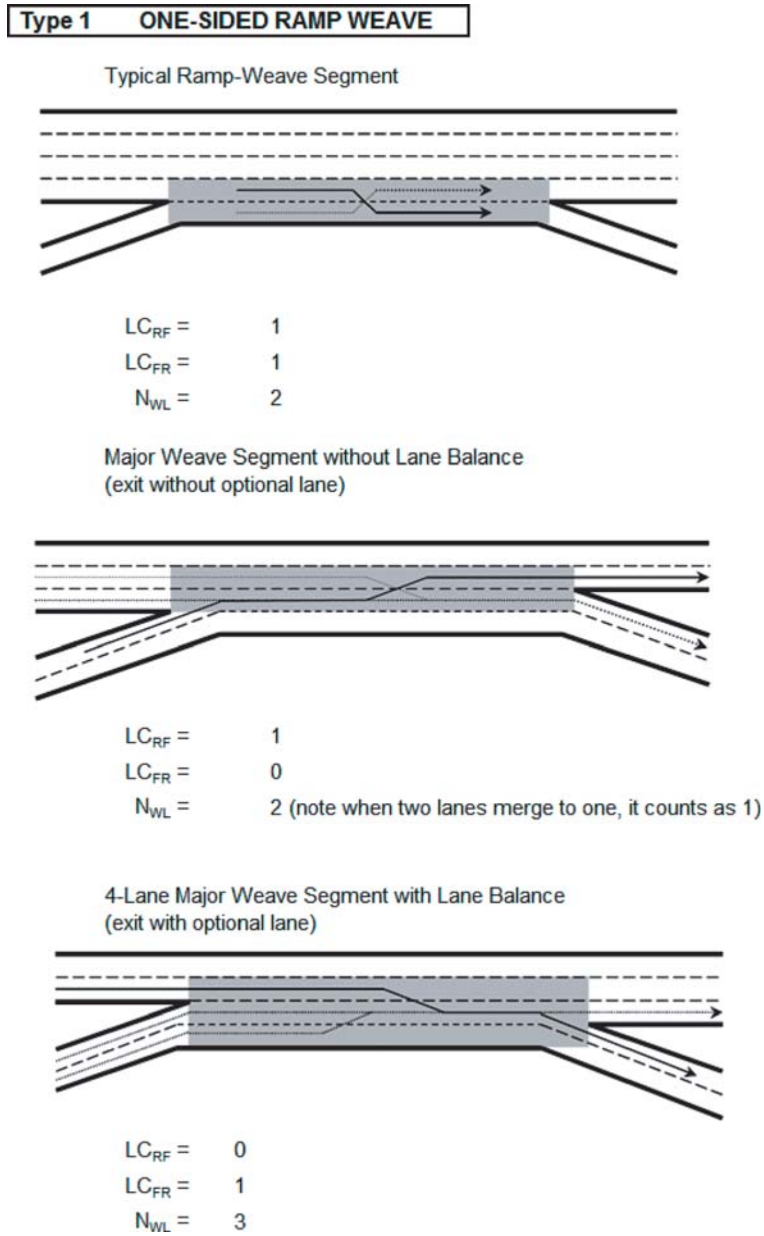


Figure 4-1. Examples of airport roadway weaving configurations.

(continued on next page)

v_{FR} = freeway-to-ramp demand flow rate in weaving segment, pc/hr.

For a two-sided weaving segment, only the ramp-to-ramp movement is functionally "weaving." The following values are established:

LC_{RR} = minimum number of lane changes that must be made by one ramp-to-ramp vehicle to successfully execute the desired maneuver.

$LC_{MIN} = LC_{RR} * v_{RR}$

v_{RR} = ramp-to-ramp demand flow rate in weaving segment, pc/hr.

Determine Maximum Weaving Length

The concept of maximum length of a weaving segment is critical to the methodology. Strictly defined, the maximum length is the length beyond which weaving turbulence no longer affects operations within the segment, or alternatively, no longer affects the capacity of the weaving segment.

$$L_{MAX} = \left[5,728(1+VR)^{1.6}\right] - \left[1,566 N_{WL}\right]$$

where VR is the ratio between weaving volume and total volume.

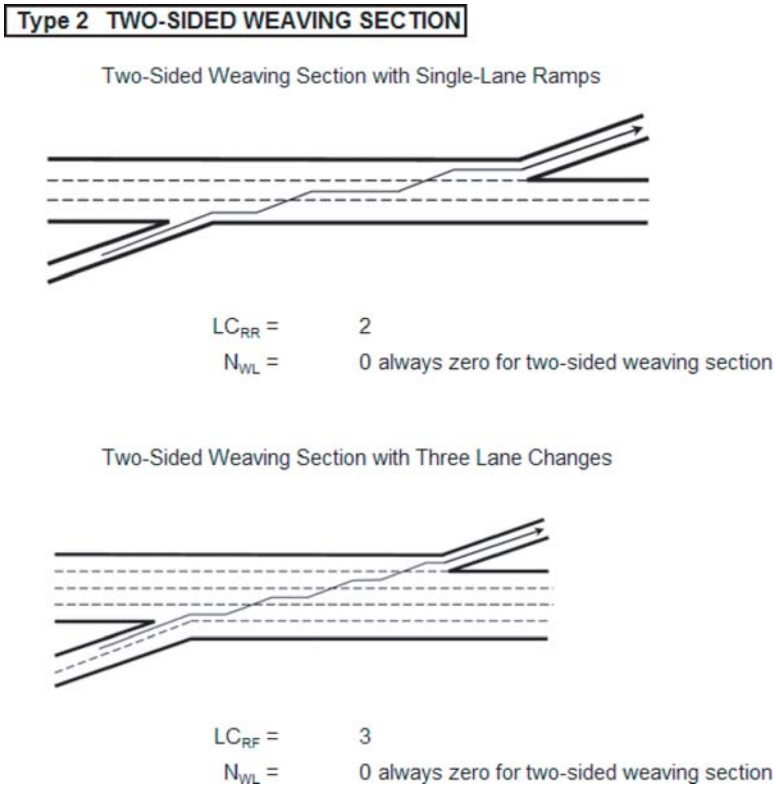


Figure 4-1. (Continued).

If the length of the weaving segment is greater than or equal to L_{MAX}, then this weaving analysis methodology is not appropriate. The segment should then be analyzed as merge, diverge, and basic segments, as appropriate.

Determine Capacity of Weaving Segment

Weaving capacity is determined by two methods: density and weaving demand flows. The final capacity is the smaller of the results of the two methods.

Weaving segment capacity determined by density. This is computed by

$$c_W = c_{IWL} * N * f_{HV} * f_P$$

where

c_{IWL} = capacity of the weaving segment under equivalent ideal conditions, per lane (pc/hr/ln)
$= c_{IFL} - [438.2(1+VR)^{1.6}] + [0.0765L_S]+[119.8N_{WL}]$.
N = number of lanes within the weaving segment.
L_S = length of the weaving segment.
c_{IFL} = capacity of a basic freeway segment with the same free-flow speed as the weaving segment under equivalent ideal conditions, per lane (pc/hr/ln), draft 2010 HCM, Chapter 11, Exhibit 11-17, and interpolated for low-speed airport access roadways.

Weaving segment capacity determined by weaving demand flows. This is computed by

$$c_W = c_{IW} * f_{HV} * f_P$$

where
$c_{IW} = 2{,}400/VR$ for $N_{WL} = 2$ lanes.
$c_{IW} = 3{,}500/VR$ for $N_{WL} = 3$ lanes.

With capacity determined, a v/c ratio for the weaving segment may be computed as follows:

$$v/c = V * f_{HV} * f_P / c_W$$

Determine Lane-Change Rates

The equivalent hourly rate at which weaving and nonweaving vehicles make lane changes within the weaving segment is a direct measure of turbulence in the flow of traffic (i.e., when vehicles exhibit irregular and apparently random fluctuations in speed). It is also a key determinant of speeds and densities within the segment, which ultimately determine the existing or anticipated level of service.

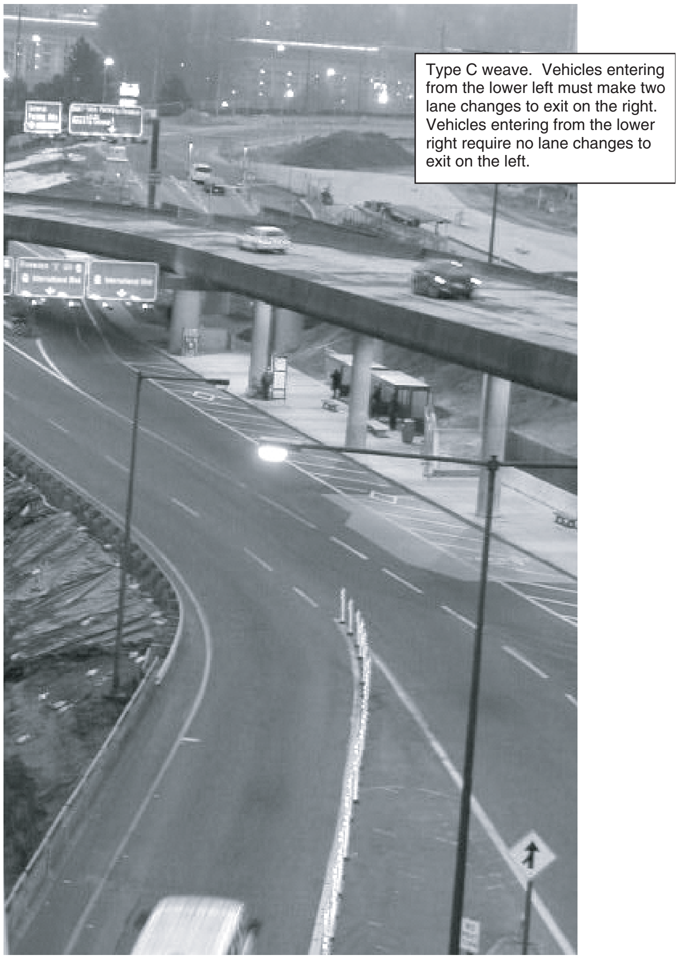


Figure 4-2. Example of weaving configurations.

Estimating the total lane-changing rate for weaving vehicles. This is computed by

$$LC_W = LC_{MIN} + 0.39\left[(L_S - 300)^{0.5} N^2 (1 + ID)^{0.8}\right]$$

where

LC_W = equivalent hourly rate at which weaving vehicles make lane changes within the weaving segment, lc/hr.

ID = interchange density, int/mi.

Estimating the total lane-changing rate for nonweaving vehicles. Two models are used to predict the rate at which nonweaving vehicles change lanes in the weaving segment:

$$LC_{NW1} = (0.206 v_{NW}) + (0.542 L_S) - (192.6N)$$

$$LC_{NW2} = 2{,}135 + 0.223(v_{NW} - 2{,}000)$$

where

v_{NW} = nonweaving demand flow rate in the weaving segment, pc/hr.

Unfortunately, these two equations are discontinuous, therefore, a third equation is introduced to bridge the gap between the discontinuity:

$$LC_{NW3} = LC_{NW1} + (LC_{NW2} - LC_{NW1})[(I_{NW} - 1{,}300)/650],$$

where

I_{NW}= a measure of the tendency of conditions to induce unusually high nonweaving vehicle lane-change rates.
= $[L_S * ID * v_{NW}] / 10{,}000$, where ID is interchange spacing per mile.

Final nonweaving vehicle lane-changing rate is defined as follows:

If	$I_{NW} \leq 1{,}300$:	$LC_{NW} = LC_{NW1}$
If	$I_{NW} \geq 1{,}950$:	$LC_{NW} = LC_{NW2}$
If	$1{,}300 < I_{NW} < 1{,}950$:	$LC_{NW} = LC_{NW3}$
If	$LC_{NW1} \geq LC_{NW2}$:	$LC_{NW} = LC_{NW2}$

Total Lane-Changing Rate. The total lane-changing rate LC_{ALL} of all vehicles in the weaving segment, in lane changes per hour, is computed as follows:

$$LC_{ALL} = LC_W + LC_{NW}$$

Determine Average Speeds of Weaving and Nonweaving Vehicles in Weaving Segment

The average speed of weaving vehicles in a weaving segment may be computed as follows:

$$S_W = S_{MIN} + [(S_{MAX} - S_{MIN})/(1 + W)]$$

where

S_W = average speed of weaving vehicles within the weaving segment, miles/hour.

S_{MIN} = minimum average speed of weaving vehicles expected in a weaving segment, miles/hour; the recommended setting for low-speed airport roadways is 10 miles/hour.

S_{MAX} = maximum average speed of weaving vehicles expected in a weaving segment, miles/hour; the recommended setting for airport roadways is the posted speed limit (unless a speed survey or field observations by the analyst indicate that a different speed is appropriate).

W = weaving intensity factor.
= $0.226 * [LC_{ALL} / L_S]^{0.789}$

The average speed of nonweaving vehicles in a weaving segment may be computed as follows:

$$S_{NW} = FFS - (0.0072 LC_{MIN}) - (0.0048\, v/N)$$

Note that usually the nonweaving speed should be modestly faster than the weaving speed. However, the developers of the draft 2010 HCM weaving methodology believe that it is acceptable for the nonweaving speed to be slightly slower than the weaving speed in some cases.

If the analyst finds that the nonweaving speed is more than 3 mph to 5 mph below that of the weaving speed, then it is recommended that the analyst recompute the weaving speed using a lower minimum speed of 5 mph (instead of 10 mph).

The average speed of all vehicles in a weaving segment may be computed as follows:

$$S = [v_W + v_{NW}]/[(v_W/S_W) + (v_{NW}/S_{NW})]$$

Determine Level of Service

The level of service in a weaving segment, as in all freeway analyses, is related to the density in the segment. Density is computed as follows:

$$D = [v/N]/S$$

where D is measured in pc/mi/ln

Density is used to look up the level of service in Table 4-3. A special set of density thresholds has been developed for weaving on low-speed airport roadways. Airport operators may choose their own thresholds based on local experience and perceptions of quality of service.

Caveats

Without more extensive research, it is impossible to know with certainty whether the results of the low-speed weaving macroscopic model presented in this section are accurate, but the results can provide an initial indication of whether a weaving section with certain parameters might operate successfully or not.

The results of the low-speed weaving analysis method and the revised metrics appear to correlate reasonably well with the observations of airport roadway weaving operations conducted as part of this research project, and produce results suitable for planning-level analyses of low-speed airport roadway weaving operations. Although low speeds can be entered as inputs to most microsimulation models, it is not known whether the resulting modeled traffic flows represent actual traffic operation patterns under those conditions—few, if any, studies have been conducted of the low-speed weaving conditions typical of airport roadways to allow full verification of the suggested low-speed weaving analysis method outputs. Significantly more observations at numerous locations are required to provide a basis for analysis of low-speed roadway weaving operations that is consistent with the level of analytical precision of the *Highway Capacity Manual* or any similar document.

The proposed low-speed weaving method is not intended to serve as a basis for any of the following:

- Design of a new low-speed roadway weaving section,
- Design of modifications to an existing low-speed weaving section,
- A definitive operational analysis of an existing or proposed weaving section, or
- The assessment of the level of safety afforded by an existing roadway.

Under the above conditions, microsimulation models may be more appropriate for evaluating traffic operations.

Table 4-3. Level-of-service criteria for weaving segments.

Level of service	Freeway weaving segments (pc/mi/ln)	Collector-distributor roadways (pc/mi/ln)	Airport low-speed roadways (pc/mi/ln)
A	10	12	20
B	20	24	30
C	28	32	40
D	35	36	50
E	>35	>36	60
F	v/c>1.0	v/c>1.0	v/c>1.0

Notes: pc/mi/ln = passenger cars per mile per lane.

If the density exceeds the LOS threshold, then the roadway is over capacity.

Source: Transportation Research Board, *Draft Highway Capacity Manual*, Exhibit 12-10, 2010 (except for airport low-speed roadways).

Use of Microsimulation Methods

Microsimulation modeling is an analytical process that uses sophisticated computer programs to analyze traffic operations for complex roadway systems. In microsimulation modeling, individual imaginary vehicles are assigned characteristics, such as a destination, vehicle performance capabilities, and driver behavioral profiles. Each "vehicle" then travels through a computerized roadway network, and various aspects of its performance are recorded during its simulated trip based on its interactions with other vehicles and traffic controls. These performance statistics can be summarized in many ways, including performance measures commonly used by traffic engineers and transportation planners (e.g., delays, travel times, travel speeds, and queue lengths).

Some aspects of roadway systems, such as intersections controlled by isolated or coordinated traffic signals, can be analyzed using simpler techniques than microsimulation. The use of microsimulation models can be beneficial in other roadway environments, including those with complex traffic movements, such as weaving operations where some vehicles are entering, some are exiting, and some are traveling through the weaving sections.

Many airport roadway systems are sufficiently complex to warrant the use of microsimulation. The use of microsimulation models should be considered if simpler analytical tools and methodologies do not yield reasonable results, provide sufficient detail, or cannot be used because the roadway configuration or operating conditions are outside the range of those addressed in the HCM. However, the use of microsimulation models and analyses of traffic using these models are relatively complex tasks requiring training in the use of the specific model and experience in traffic engineering to fully understand the simulation process so that appropriate inputs are used and the outputs are interpreted correctly. Most microsimulation software packages also require significant time to learn.

Suggested guidelines on when microsimulation is probably not needed are as follows:

1. Signalized or unsignalized intersections can usually be analyzed using methodologies in the 2000 HCM unless exclusive left-turn lane storage area overflows are a significant problem. In such cases, HCM methodologies may yield optimistic estimates of signal performance, and microsimulation modeling may yield more accurate results.
2. Roadway segments having few or no driveways or intersecting side roads.
3. Weaving segments with two entries and two exits and a reasonable distance (e.g., at least 500 feet) between the entrance to, and exit from, the segment, and free-flow speeds of 35 mph or greater.
4. If the use of a simpler technique—even if the inputs are outside of the recommended ranges—yields outputs that are consistent with observed conditions (e.g., traffic seems very congested, and use of the HCM methodology yields LOS E or F).

Guidelines regarding when to consider microsimulation:

1. Signalized or unsignalized intersections that have more than four legs or are oriented in atypical ways. The analyst should initially attempt to use HCM methodologies and then consider microsimulation modeling if the inputs required to evaluate the roadway segments do not correspond to the HCM analysis structure.
2. Airport roadway segments with the number of lanes changing along the length of the segment and with multiple, and possibly unusual, orientations of driveways or intersecting side roads.
3. Weaving segments that do not fit the orientation of the weaving analysis in the HCM. This could mean more than two entries or exits, dimensions or speeds outside the bounds defined in the HCM, signals or stop signs within the weaving segment, etc.
4. If simpler techniques are used to analyze what appear to be sufficiently simple facilities, but the results indicate operations that are much worse or much better than those observed.
5. When congestion on one roadway section causes queues or backups that extend back and interfere with operations on an upstream critical roadway section.
6. When congestion on one roadway section significantly restricts the volume of vehicles that can arrive at a downstream critical location.
7. When comparing the congestion resulting from different improvement options for situations where it is not possible to design sufficient capacity to eliminate significant congestion. In this case, comparisons are typically made of the extent of the congestion (duration and length of queues) produced by the various improvement options. Microsimulation modeling is the best available tool for making these comparisons.

FHWA's *Traffic Analysis Toolbox III: Guidelines for Applying Traffic Microsimulation Modeling Software* (FHWA-HRT-04-040, July 2004) provides additional information on the use and application of microsimulation. This document is available at http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol3/index.htm.

Other Performance Measures

At some airports, the adequacy of a roadway or curbside area has been defined by the length of time a motorist requires to enter and exit the terminal area. Microsimulation models can be used to establish a baseline condition and compare the baseline travel time (or a predetermined acceptable travel time) with the travel times resulting from different levels of traffic demand and access and circulation roadway configurations. However, it is difficult to accurately estimate these travel times and queues without the aid of microsimulation models because of the relative short distances being analyzed and the difficulty in estimating queue lengths through other means.

CHAPTER 5

Evaluating Airport Curbside Operations

This chapter presents measures of curbside roadway performance, definitions of curbside roadway levels of service, and a hierarchy of analytical methods for estimating curbside roadway capacities and levels of service. It also describes use of a macroscopic method, QATAR, for analysis of airport curbside roadways, and explains the use of this method. Appendix G documents the queuing theory and assumptions used in QATAR.

In evaluating airport curbside roadway operations, analyses of both the curbside lanes (where motorists stop to pick up or drop off passengers) and the adjacent through lanes are required. As described in Chapter 2, these analyses are necessary because double- or triple-parked vehicles impede or delay the flow of vehicles in the adjacent through lanes.* As a result, the capacity of the through lanes decreases as demand for curbside space approaches or exceeds the capacity of a curbside roadway segment, causing double or triple parking.

As described in more detail later in this chapter, the capacity of curbside pickup and drop-off areas depends on the number of lanes airport management allows to be used for vehicles to stop, load, or unload. For example, at airports where double parking is prohibited, curbside capacity equals the effective length of the lane next to the curb. At airports where double parking is allowed, curbside capacity equals twice the length of this lane.

In this chapter, methods of estimating the volumes, capacities, and levels of service of the curbside lanes and the through lanes are presented separately. However, when estimating airport curbside roadway capacities and levels of service, it is necessary to consider the operations of both the curbside lane and the through lanes concurrently because the capacity and level of service of an airport curbside roadway system is determined by the component that has the lowest capacity or provides the poorest level of service.

The methods and data presented in this chapter represent the best available information concerning airport roadway operations and the consensus of the research team, the Project Panel, and other reviewers. It is suggested that additional research be conducted to refine the estimated airport curbside roadway maximum service rates (i.e., the maximum flow rates at each level of service).

Performance Measures

Curbside utilization is the recommended performance measure for airport curbside roadways. Curbside utilization indicates the ability of a roadway to accommodate existing or projected requirements for vehicles loading or unloading at the curbside. It also indicates if spare capacity is available to serve additional demand and surges in demand.

Roadway and curbside capacities are typically analyzed for the peak hour or design hour of a facility. For airport roadways, it is suggested that the design hour be a typical busy hour on the peak day of the week during the peak month. This suggestion is in contrast to planning for airfield and other airport facilities, which often considers the peak hour of an average day during the peak month.

Typically, a utilization factor of 1.30 or less (65% of the capacity of the curbside loading/unloading lanes) is a desirable planning target for new curbside roadways. A utilization factor of 1.70 (85% of the combined capacity of the inner and second curbside lanes) is acceptable for existing facilities, recognizing that during peak hours and days of the year, demand will exceed capacity. However, individual airport operator policies regarding parking in multiple lanes may dictate different utilization factor planning targets.

*Throughout this chapter, the term "parked vehicle" refers to a vehicle that has come to a complete stop and remains stopped to allow the loading or unloading of passengers and their baggage. Vehicles on curbside roadways are not "parked" in the same sense as vehicles in a parking lot or an on-street parking space because these parked vehicles may not be left unattended on airport curbsides. Within the airport industry, vehicles stopped or standing at curbsides are commonly referred to as parked vehicles.

Utilization is an indicator of curbside roadway level of service, which provides an overall indication of the quality of the experiences of drivers and passengers using the curbside roadway. LOS C is a desirable planning target for a medium- or small-hub airport, both for the design of new curbside roadways and for analyzing an existing facility. LOS D is acceptable for an existing curbside roadway at a large-hub airport, recognizing that on some peak days of the year, the level of service may decrease to LOS E or less. Level of service is estimated separately for through traffic and for curbside loading/unloading traffic.

When additional performance measures, as described below, are required to supplement curbside utilization, the analysis is conducted using a microsimulation model. Such supplemental measures cannot be accurately determined without the use of a microsimulation model, either quantitatively or in the field (i.e., they are difficult to quantify using field surveys). For example, the use of a microsimulation model would help document the ability of an existing curbside roadway to accommodate future demand, or to quantify the benefits resulting from alternative curbside improvement options. These supplemental performance measures include

- **Number of vehicles parked in the second and third lanes.** The number of through lanes blocked by parked or parking vehicles (and the proportion of the modeled hour during which this blockage occurs) is an indicator of the extent of roadway congestion. It is also an indirect indication of the ability of motorists to enter/exit and stop at their preferred curbside locations since it is difficult for motorists stopped in the curb lane to exit when triple parking occurs without the intervention of traffic control officers.
- **Queue length.** Queue length is the number of vehicles waiting to enter the curbside roadway or a specific curbside parking area expressed in terms of the distance that the vehicle queue extends back from the curbside parking area or point of congestion. Queue lengths are estimated for different levels of probable occurrence. The mean queue length has a 50% probability of being exceeded some time during the hour. The 95% queue length has a 5% probability of being exceeded. The 95% queue length is typically used for design purposes.
- **Queuing duration.** The queuing duration (in minutes) indicates how long the congestion will last, and is useful for comparing two potential design solutions, neither of which completely eliminates queuing. Ideally, the queuing duration is zero for a new curbside roadway, and less than one hour for an existing curbside roadway.
- **Average vehicle delay.** Average vehicle delay consists of two components—through traffic delay and curbside loading/unloading delay.

  Through traffic delay is the amount of time required for a vehicle to traverse the entire curb length. To determine through traffic delay, the unimpeded travel time for through traffic on the curbside roadway is subtracted from the actual travel time to obtain the amount of through traffic delay per vehicle. When designing a new curbside roadway, the delay to through traffic should ideally be near zero. For existing roadways, delays of up to 15 seconds per vehicle may be acceptable, recognizing that the delays could be significantly higher on peak days of the year. The acceptable amount of delay for through vehicles must be set by the airport operator based on the design of the landside circulation system and the number of other delays experienced by through vehicles on other portions of the roadway circulation system. For example, if through vehicles must pass several curbside loading/unloading areas, then delays at each curbside area will be less tolerable.

  Curbside loading/unloading delay is the amount of time a vehicle requires to pull into a curbside stall, load or unload passengers, and exit. The minimum time necessary to drop off or pick up a passenger during uncongested periods (i.e., the average dwell time) should be subtracted from the total average observed time to obtain the amount of curbside loading/unloading delay. Curbside delays of up to 30 seconds are acceptable when designing a new roadway. Delays of up to 60 seconds per vehicle are acceptable for existing roadways.

As shown by the checkmarks in Table 5-1, use of these performance measures requires different analysis methods. When curbside roadways are being analyzed using microsimulation models, it is possible to consider the number of vehicles parked in the second and third lanes, the length and duration of curbside queues, and average vehicle speeds (or delays). Without the aid of microsimulation models, it is difficult to accurately estimate vehicle parking patterns, travel times and delays, and queue lengths because of the relatively short distances on curbside roadways being analyzed and the difficulty estimating queue lengths through other means. When curbside roadways are being analyzed using the quick-estimation or macroscopic methods described in this chapter, the appropriate performance measures are curbside utilization and the corresponding levels of service.

Level-of-Service Definitions for Airport Curbside Roadways

The primary element defining the level of service of an airport curbside roadway is the ability of motorists to enter and exit the curbside space of their choice (e.g., one near their airline door or other chosen destination). As roadway demand

Table 5-1. Recommended airport curbside performance measures.

Performance measure	Quick estimation	Macroscopic analysis	Microsimulation analysis
Curbside utilization ratio	✓	✓	✓
Number of vehicles parked in second and third lanes			✓
Queue length			✓
Queuing duration			✓
Average vehicle delay			✓

and congestion increase, motorists are required to stop in spaces farther away from their preferred destination. The motorist is required to either stop in a downstream or upstream curbside space, double park, or, in an extreme case, circle past the curbside area multiple times while searching for an empty space.

The key performance measures defining the level of service of an airport curbside roadway are the

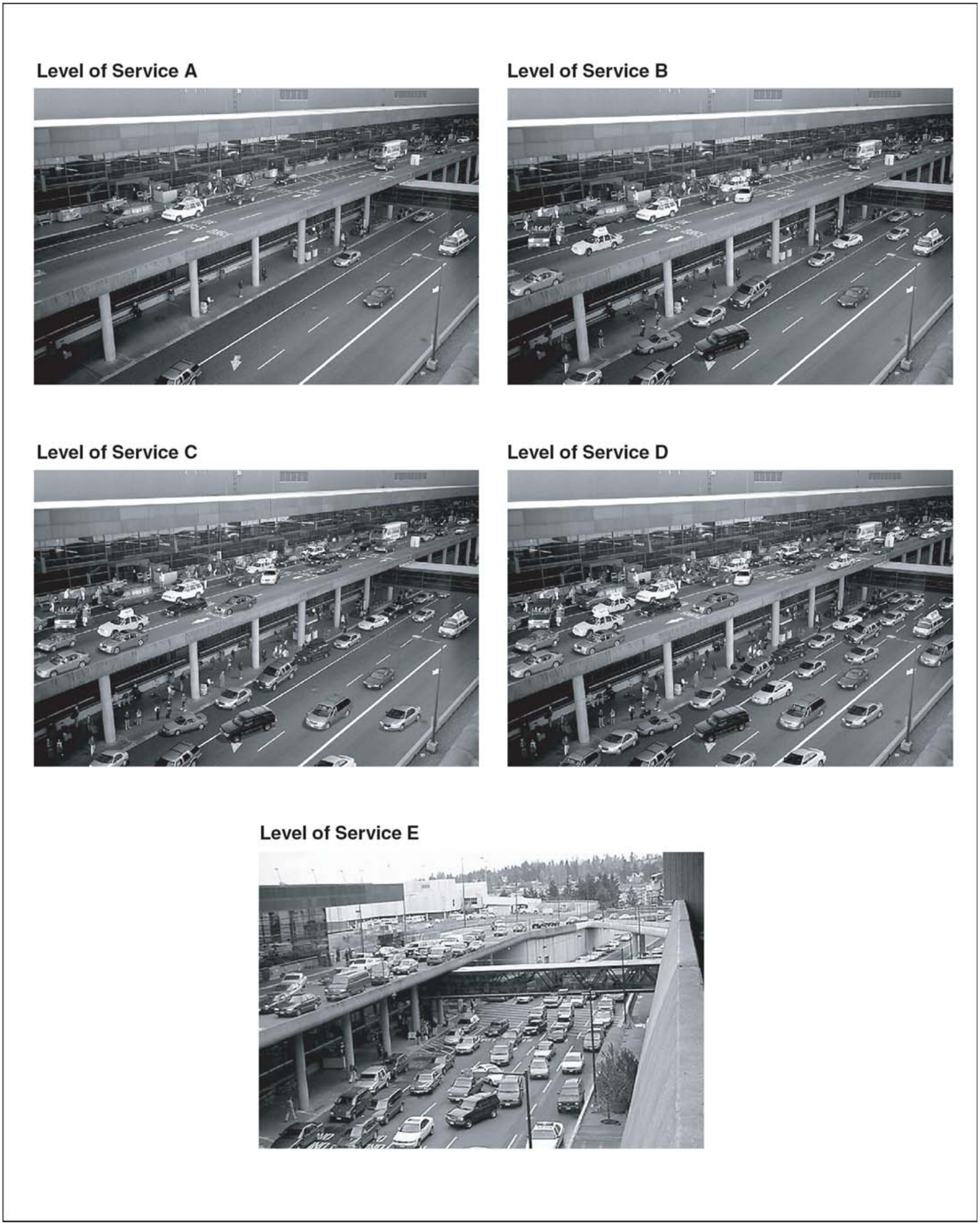
- Number of vehicles parked or stopped in the curbside lane, and the percent double or triple parked, or otherwise stopped, in a position that interferes with the flow of traffic in adjacent lanes. This number of parked vehicles is a function of curbside demand vs. available capacity.
- Length and duration of queues at the entrance to the curbside area.
- Average delay encountered by private and commercial vehicles entering and exiting the curbside areas.
- Curbside utilization ratio, which is a comparison of the length of the vehicles stopped along the curbside and the effective length of the curbside (i.e., the total length less the space occupied by crosswalks or other areas in which vehicles, or certain classes of vehicles, cannot stop).

As stated, most of these measures are obtainable only through microsimulation modeling. Therefore, level-of-service definitions for airport curbside roadways shown in Figure 5-1 and presented in Table 5-2 are based on curbside utilization ratios. These definitions and ratios were validated using focus groups of airline passengers, airport landside managers, and commercial vehicle operators, which were conducted as part of this research project. (Appendix E presents a summary of these focus group sessions.)

Estimating Airport Curbside Roadway Traffic Volumes

Curbside roadway traffic volumes can be estimated using the same methods used to estimate airport terminal area roadway traffic (see Chapter 3): the traditional four-step travel forecasting method and the growth factors method. The key differences between estimating terminal area roadway traffic and curbside roadway traffic include, for curbside roadway traffic, the need to prepare the following:

- **Separate estimates of vehicles stopping in a curbside lane and through traffic vehicles.** At small airports with a single terminal building and a short curbside area (e.g., less than 500 feet in length), the volume of through vehicles may equal the volume of vehicles stopping at the curbside. However, these volumes may differ at airports having (1) multiple terminal buildings or large concourses served by a common roadway, (2) a curbside area with inner and outer curbside roadways separated by a raised island with midpoint entrances and exits, or (3) curbside roadways that are used by non-curbside traffic (e.g., vehicles entering or exiting parking areas, rental car areas, or other facilities).
- **Separate analyses of the departures curbside and arrivals curbside roadways.** It is necessary to analyze these curbside areas separately because the departures and arrivals peak periods at an airport (and thus peak periods of curbside demand) occur during different hours of the day, and vehicle dwell times and space allocations (the proportion of curb length assigned to individual classes of vehicles) differ significantly at the departures and arrivals curbside areas, as described in subsequent sections of this chapter. At airports with dual-level curbside roadways, separate analyses of each level are required. At airports with a single-level curbside roadway, analyses of the peak periods for originating, terminating, and total passengers (originating plus terminating) are required.
- **Separate analyses for each class of vehicle.** Private vehicles, taxicabs, limousines, door-to-door vans, courtesy vehicles, and charter buses/vans each have different dwell times, required vehicle stall lengths, and maneuvering capabilities. Furthermore, each service provided by these vehicles may have different operational methods and be governed by different airport regulations. For example, on an arrivals curbside, an airport operator may permit taxicabs to stand at the curbside for 30 minutes or more to ensure that waiting vehicles are available for arriving customers and may allow charter buses to remain at the curbside for 10 to 15 minutes to ensure that all members of a large party have claimed their bags and boarded the vehicle, but may only allow



Source: LeighFisher.

Figure 5-1. Curbside levels of service.

Table 5-2. Level of service criteria for airport curbside roadways.

Criteria	Airport curbside levels of service A	B	C	D	E	F
When double (and triple) parking is allowed at the curbside						
Maximum demand for curbside standing or parking/effective curbside length (*a*)	0.90	1.10	1.30	1.70	2.00	>2.00
Maximum service flow rate						
5-lane curbside roadway (vph)	3,400	3,280	3,100	2,710	2,400	Up to 2,400
4-lane curbside roadway (vph)	2,830	2,790	2,680	2,220	1,800	Up to 1,800
3-lane curbside roadway (vph)	2,200	1,950	1,580	860	750	Up to 750
When double parking is prohibited at the curbside						
Maximum demand for curbside standing or parking/effective curbside length (*a*)	0.70	0.85	1.00	1.20	1.35	>1.35
Maximum service flow rate						
4-lane curbside roadway (vph	2,830	2,830	2,800	2,730	2,600	Up to 2,600
3-lane curbside roadway (vph)	2,350	2,250	2,000	1,760	1,600	Up to 1,600
Maximum through lane volume/capacity ratio	0.25	0.40	0.60	0.80	1.00	1.00

vph = vehicles per hour

(*a*) The ratio between the calculated curbside demand and the available effective curbside length.

Source: Jacobs Consultancy, November 2009.

hotel/motel courtesy vehicles to stop while actively boarding passengers.

- **Separate estimates of traffic volumes for each terminal building or concourse.** The peak periods of activity for each airline serving an airport may occur during different hours of the day. At airports with multiple terminals or large concourse(s) dominated by a single airline, the largest traffic volumes (and curbside area requirements) may occur during a different hour (or different 15-minute period) at each terminal or near each concourse. In addition, motorists prefer to stop at the curbside area nearest the doors (or skycap podiums) serving their airline (or that of the passenger they are transporting). Thus, demands are not distributed uniformly along the length of a curbside—particularly at airports with multiple terminals or large concourses—but are concentrated at the curbside areas corresponding to the airlines serving the largest volume of passengers during the peak period.

  As a result, at airports with several terminals or multiple concourses, the traffic volumes and curbside area requirements that correspond to (or are generated by) each terminal or concourse should be estimated. These estimates can be prepared by allocating the total peak-hour traffic volumes to each curbside area according to the percentage of total demand served by each area during the peak hour. The percentage of total demand served by each area can be estimated by analyzing (in decreasing order of reliability) the proportion of (1) peak period originating (or terminating) passengers served by each terminal building or concourse, (2) the number of scheduled aircraft seats served by terminal or concourse during the peak period, or (3) the number of aircraft gates served by each concourse.

If the data are available, it is preferable to estimate the traffic volumes generated by each terminal curbside area (by type of vehicle) separately, as the demographic and/or travel mode choices of the passengers on each airline may differ. For example, the curbside operations at a terminal primarily serving international passengers will differ from curbside operations at a terminal serving regional aircraft or short-haul domestic flights. However, as stated in Chapter 3, such airline passenger data require surveys of airline passengers and are available at few airports.

Estimating Airport Curbside Roadway Capacity and Level of Service

Estimating airport curbside roadway capacities and levels of service requires analyses of both the curbside lanes and the through lanes because the numbers of vehicles parked in the curbside lanes affect the flow of vehicles in the through lanes; as curbside lanes approach capacity, the capacity of the adjacent through lanes is reduced.

The capacity of a curbside roadway is defined as the smaller of (1) the number of vehicles that can be accommodated in the curbside lane(s) designated for loading or unloading or (2) the volume of through vehicles that can be accommodated in the through lanes.

Establishing Curbside Lane Capacity

Curbside lane capacity is typically estimated in terms of the area (and the number of lanes) that the stopped vehicles may occupy while loading or unloading. Since vehicles stop in a nose-to-tail manner at most airports, this area is described as the effective length of curb measured in linear feet. Effective length is defined as the total length of the lane less (1) any space unavailable for public use because it is reserved for crosswalks, disabled motorists, or specific classes of vehicles (e.g., taxicabs or public buses) and (2) space located beyond the ends of the terminal building or adjacent to columns or other physical barriers that discourage its use by motorists because passengers cannot easily open their doors or easily enter/exit a vehicle.

The number of stopped vehicles that can be accommodated in the curbside lane(s) (i.e., the capacity of the curbside lanes) varies depending on the number of lanes in which airport operators allow vehicles to routinely stop to load or unload passengers and their baggage. Airport operators establish specific policies concerning double parking that reflect the width of their curbside lanes, enforcement policies and capabilities, customer service, and use by private and/or commercial vehicles.

Airports Where Double Parking Is Prohibited

At airports where double parking is prohibited, the number of vehicles that can be accommodated in the curbside lane is equal to the effective length of a single curbside lane. Some airport operators restrict curbside parking or standing to a single lane for operational reasons (e.g., a narrow curbside roadway or curbsides used exclusively by commercial vehicles where double parking is prohibited).

This description of the number of vehicles that can be accommodated in the curbside lane also applies to curbside roadways with a maximum of three lanes. This is because on a curbside roadway with three lanes only a single through lane would be available if double parking were to occur, which would lead to frequent bottlenecks (e.g., when a double-parked vehicle or an open door of such a vehicle intrudes into the third lane). Thus, a single through/maneuvering lane for a significant portion of the curbside length is considered unacceptable and double parking is generally not tolerated on curbside roadways with a maximum of three lanes.

Airports Where Double Parking Is Allowed

At airports where double parking is allowed on the curbside roadways, the number of vehicles that can be accommodated at the curbside is equal to twice the effective curbside length. At airports where double parking is regularly allowed, pavement markings typically have been installed designating the lane next to the sidewalk plus the adjacent lane for passenger drop-off or pickup, or where enforcement policies allowing double parking have been established.

On roadways where double parking is allowed, if the roadway were operating at full capacity, the stopped vehicles would not be evenly distributed along the length of the two curbside lanes, and some motorists would choose to triple park next to the most desirable doorways or other locations.

Additional Considerations

At airports with inner and outer curbside areas available for use by private vehicles, these areas have different effective capacities, even if they are the same length. Motorists prefer to stop at the most convenient space available (e.g., the inner curbside lane), even if they observe downstream congestion or delays on this roadway. Thus, it is necessary to "discount" the capacity of the outer, less convenient curbside area if both areas are allocated to private vehicles. If one curbside is allocated to private vehicles and the second is allocated to commercial vehicles, such discounting is not required.

For example, motorists approaching the departures curbside at Salt Lake City International Airport can use the curbside area adjacent to the terminal building or an alternative curbside area within the adjacent parking garage. Passengers using the alternative curbside are provided with a grade-separated path to/from the terminal building and are offered skycap service on Delta Air Lines. Notwithstanding the good access, good directional signage, and amenities available, motorists are reluctant to use the curbside area within the parking garage, even when the curbside area adjacent to the terminal is congested.

Consequently, it is suggested that, when calculating the capacity of a similar curbside configuration at other airports, it is necessary to adjust (or discount) the actual length of curb space within a garage (or other supplemental location) to determine its effective capacity. This adjustment is necessary because, if both the primary and supplemental curbsides are allocated for private vehicle use, the supplemental curbside will provide less capacity (even though it may be the same length) than curb space adjacent to the terminal building because it attracts fewer passengers. This discount factor is similar to operational factors, presented in the 2000 HCM, used to calculate roadway capacity and account for population factors, lane widths, rolling terrain, or unfamiliar drivers.

No published research provides guidance on this discount factor, but the factor appears to vary according to the traffic queues caused by downstream congestion, local enforcement policies, availability of skycap service and dynamic signage, and the demographics of the passenger market (e.g., the proportion of frequent travelers or those traveling primarily with carry-on baggage). It is suggested that analyses be guided by field observations of existing conditions, which would reflect the unique characteristics of the airport and its passengers. If field data are unavailable, it is suggested that the capacity of the supplemental curb space located in a garage be discounted by 50% and that the capacity of an outer curbside be discounted by 20% to 30%.

Alternative Curbside Configurations

It is assumed in the above discussions that vehicles stop in the curbside lane in nose-to-tail configuration. However, at some airports, the curbside areas are configured with pull-through spaces or 45-degree stalls. (See Chapter 2 for illustrations of alternative curbside configurations.) The above methods are applicable to these configurations with the exception of the sample vehicle dwell times and through-lane capacities discussed in the following section.

Calculating Curbside Lane Requirements

Quick-Estimation Method

This method is appropriate for use during the early planning and design stages for a new curbside when little is known about the details of the curbside design or layout. This method is used to compute the curb length required to serve a given demand, but it does not provide specific results on performance, such as average delay or queuing probability.

A curbside lane can be considered as a series of stopping spaces, each capable of accommodating one vehicle. The average number of vehicles each space can serve during a given time period is inversely proportional to the average length of time (referred to as the vehicle dwell time) a vehicle occupies a space. For example, if the average vehicle dwell time is 3 minutes, then each space can accommodate, on average, 20 vehicles per hour. If the peak-hour volume is 160 vehicles, then (with the assumed average dwell time of 3 minutes per vehicle), the required curbside length is equivalent to eight spaces or 200 linear feet (assuming an average space length of 25 feet for illustrative purposes). This can be represented mathematically as

$$R_a = V * D_i / 60 * L$$

where

R_a = the average curbside length required to accommodate the vehicles stopping at a curbside area.

V = the hourly volume of vehicles stopping at a curbside area.

D_i = the average vehicle dwell time (in minutes).

L = the average vehicle stall length.

This formula represents a condition where a single class of vehicles is using a curbside area (e.g., a curbside serving private vehicles exclusively), or where the requirements are developed assuming that all vehicles can be represented using average dwell times and a single stall length. More accurate estimates can be developed by considering, separately for each class of vehicle, the hourly volume, the distribution of dwell times (rather than average dwell time), and average vehicle length. Additional accuracy can result from consideration of the peak periods within the peak hour (e.g., analysis of the peak 15 or 20 minutes) and the nonuniform distribution of demand along the curbside lane caused by a concentration of traffic at specific airline doors or other attraction points. The nonuniform arrival rate and distribution of vehicles can be reflected using statistical factors (e.g., a Poisson distribution).

Table 5-3 presents data, gathered at the airports serving Memphis, Oakland, Portland, San Francisco, and Washington, D.C. (Dulles), used to calculate curbside lane requirements by class of vehicle, the application of a Poisson distribution (or adjustment) factor, and the resulting curbside requirements. The table presents examples of average curbside dwell times and vehicle stall lengths based on observations of post-2001 curbside roadway operations at the airports, the estimated curbside requirements (i.e., design length) for five zones (two zones on the enplaning curbside and two zones plus a courtesy vehicle lane on the deplaning curbside). A comparison of the estimated requirements with the available curb length yields utilization factors for each of the five zones. As shown, two of the zones are substantially over capacity as evidenced by the utilization factors over 2.0.

The quick-estimation method involves the following steps:

1. Determine peak-hour traffic volume from field survey or estimates of future traffic.
2. Determine the vehicle mix. If vehicle mix is unknown, assume that private vehicles represent 70% to 80% of the total traffic volumes, taxicabs and limousines represent 5% to 10%, courtesy vehicles represent 5% to 10%, and vans/buses/public transit represent 5%.
3. Determine the average vehicle stall length. Use the de facto values shown in Table 5-3 or the QATAR model (see Figure 5-3) or measure representative values, particularly for unusual vehicles or atypical parking configurations.
4. Determine vehicle dwell times using field measurements or the de facto dwell times shown in Table 5-3 or the QATAR model (see Figure 5-3).
5. Calculate curbside stall requirements that are equal to the volume multiplied by vehicle dwell times divided by 60 minutes.
6. Determine curbside design stall requirements that are equal to the curbside stall requirements times a probabilistic factor applied to the total curbside stall requirements (if a mixed-use curbside such as a typical departures curbside) or to an individual class of vehicles (if curb space is allocated to this classification), ranging from 3.0 for requirements less than 5 curbside stalls to 1.2 for curbside stall requirements of 100 or more.

Table 5-3. Estimate of terminal building curbside requirements—sample calculation.

Mode	Hourly volume (vph)	Average curbside dwell time (minutes)	Required curbside stalls	Required design stalls (*a*)	Vehicle stall length (feet)	Design length (feet)	Existing curb length (feet)	Curbside utilization factor
Enplaning level, north								
Private vehicles	621	3	31.0	40	25	1,000		
Taxicabs	52	2	2.0	5	25	125		
Limousines	9	2.5	0.4	2	30	60		
Door-to-door vans (*b*)	38	3	1.9	3	30	90		
Courtesy vans (*b*)	24	4	1.6	3	30	90		
Scheduled buses (*b*)	10	5	0.8	1	50	50		
Total	754					1,415	600	2.36
Enplaning level, south								
Private vehicles	363	3	18.0	25	25	625		
Taxicabs	35	2	1.0	3	25	75		
Limousines	6	2.5	0.3	1	30	30		
Door-to-door vans (*b*)	38	3	1.9	2	30	60		
Courtesy vans (*b*)	24	4	1.6	3	30	90		
Scheduled buses (*b*)	10	5	0.8	1	50	50		
Total	476					930	830	1.12
Deplaning level, north								
Private vehicles	580	5.2	50.0	62	25	1,550		
Limousines	5	5.2	0.4	1	30	30		
Total	585					1,580	535	2.95
Deplaning level, south								
Private vehicles	345	5.2	30.0	39	25	975		
Limousines	4	5.2	0.3	1	30	30		
Total	349					1,005	780	1.29
Deplaning level courtesy vehicle lane								
Courtesy vehicles (*b*)	223	1	4	8	30	240	300	0.80

(*a*) Represents calculated stall requirements adjusted to reflect random arrival of vehicles and nonuniform distribution of traffic volumes and demands using Poisson statistical probability factors.
(*b*) Assumes that this mode makes a single stop at the curbside.

Source: LeighFisher, November 2009.

7. Determine curbside design length that is equal to the number of design stalls times the average vehicle stall length
8. Calculate the utilization factor that is equal to the curbside design length divided by the existing curb capacity (or effective length) considering whether double parking is allowed by the airport operator. As defined previously in this chapter, a curbside utilization factor equal to or less than 1.3 is considered acceptable for a new design, while a utilization factor equal to or less than 1.7 is considered acceptable for existing curbside roadways.

Macroscopic Method

Alternatively, the curbside lane can be considered a series of processing points (or servers) and traditional queuing analyses can be used to calculate the capacity of individual servers and the total capacity of the curbside lane. The macroscopic method (QATAR) described in the upcoming section on Analytical Framework Hierarchy for Airport Curbside Roadways uses queuing analysis to estimate curbside capacity.

The following subsections describe the calculations of through-lane capacity and curbside capacity.

Calculating Through-Lane Requirements

The requirements for curbside roadway through lanes depend on the areas they serve. At airports with a single terminal building and a short curbside area, the volume of through vehicles may equal the volume of vehicles stopping at the curbside. As discussed in previous chapters, factors that may result in higher volumes of traffic in the through lanes include vehicles bypassing a curbside area (1) that does not serve their airline (e.g., a different terminal building or major concourse), (2) that is reserved for other classes of vehicles (e.g., authorized commercial vehicles), or (3) to enter or exit parking, rental car, or other land uses not related to curbside activities. As noted, bypass traffic proceeding to another terminal (as opposed to through traffic proceeding to a downstream portion of the curbside lane) may represent a significant portion of the total curbside roadway traffic volume. When these conditions occur, it is necessary to use the methods described in Chapter 4 to estimate the volume of traffic associated with the alternative land uses and/or to assign traffic volumes to each curbside roadway section (or airline) and class of vehicle.

The capacity of a curbside roadway through lane is measured using methods similar to those described in Chapter 4 for other airport terminal area roadways, adjusted to account for the presence of double- or triple-parked vehicles. As noted previously, double- and triple-parked vehicles block or delay the movement of vehicles in through lanes, because through traffic must decelerate and maneuver around these stopped vehicles. As a result, through-lane capacity decreases when curbside lane demand exceeds the available capacity of a specific curbside segment (as opposed to the entire curbside length), and vehicles are double or triple parked.

The reduction in through-lane capacity resulting from increased curbside lane demand can be estimated using commercially available microsimulation models capable of simulating airport curbside roadways or using QATAR (discussed later in this chapter). Alternatively, the approximations shown in Table 5-2 can be used to estimate curbside roadway lane capacities.

Curbside roadway capacity must also be reduced when at-grade pedestrian crosswalks are present. The extent of the capacity reduction is a function of the volume of pedestrians crossing the roadway since the amount of time motorists must wait for pedestrians increases with pedestrian traffic. For example, if a crosswalk is controlled by a traffic signal, and if the signal allocates 25% of the green time during each hour to pedestrians, then capacity of the curbside roadway would be 25% less than if there were no crosswalk. If, instead of a signal, crosswalk operations are controlled by a traffic control officer, then a similar approximation can be made by observing curbside roadway operations. If the crosswalk is uncontrolled, then the behavior of motorists (do they stop when a pedestrian enters a crosswalk?) and the volume of pedestrians need be considered.

Additional Considerations in Estimating Commercial Ground Transportation Vehicle Curbside Requirements

The analytical methods used to estimate curbside traffic volumes presented in Chapter 4 are applicable to private vehicles and commercial ground transportation vehicles, the volumes of which can be directly correlated to airline passenger demand (e.g., limousines, taxicabs, and door-to-door vans dropping off passengers). However, these analytical methods are not applicable to vehicles that are allowed to remain at the curbside for extended periods (e.g., taxicabs and door-to-door vans standing in queues waiting to pick up passengers) or that operate on a scheduled or de facto scheduled basis (e.g., courtesy vehicles that generally operate on fixed headways regardless of the number of passengers transported).

Allocation of Curb Space

Generally, airport operators do not reserve space for commercial ground transportation vehicles dropping off airline passengers, with the exception of vehicles, such as public buses, that drop off and pick up passengers at the same curbside space. The amount of space allocated to commercial ground transportation vehicles picking up passengers is generally determined by airport management considering such factors as

- **Customer expectations.** Deplaning airline passengers generally expect taxicabs to be available immediately adjacent to the baggage claim area, or visible from the exit doors. Passengers who have reserved luxury limousines expect a higher level of service than those choosing public transportation (e.g., baggage assistance, shorter walking times, minimal wait time).
- **Operational needs.** To minimize the wait times of deplaning passengers, taxicabs are generally allowed to wait at the deplaning curbside area in queues of 3 to 10 vehicles. The number of taxicabs in the queue is a function of airport policy, the proximity of a taxicab hold area (where additional taxicabs may wait until dispatched to the curb), and the availability of curb space. Similarly, door-to-door vans are generally allowed to wait at the deplaning curbside, with the number of vans a function of the number of regional destinations served, number of van companies, airport policies, and available curb space.
- **Space requirements.** In analyzing the amount of space to be allocated to each class of commercial vehicle operator (e.g., hotel/motel courtesy vehicles), the number of vehicles that will use the space concurrently (which is based on the number of operators and the frequency with which they serve the airport), and the permitted vehicle dwell times and vehicle sizes must be considered.
- **Vehicle maneuverability.** In determining the amount of curb space to be allocated to each class of commercial vehicle operator, consideration should be given to the maneuverability requirement of the vehicles used (e.g., vans,

minibuses, or full-size buses) and, if appropriate, requirements of access to baggage compartments or baggage trucks. For example, a 45-foot-long full-size bus requires about 60 feet to stop parallel to a curb space. If a bus has an under-the-floor baggage storage compartment, curb spaces should be configured so that columns, sign poles, or other obstacles do not interfere with the opening of the baggage compartment.

- **Vertical clearances.** The ability of a full-size bus or other large vehicle to use a curbside area may be limited by the vertical clearance available (including low-hanging signs or drainage structures). For example, the minimum vertical clearances required are 13 feet for a full-size bus, 11.5 feet for the shuttle buses used by rental car companies, and 9 feet to 10 feet for courtesy vans serving hotels/motels. These dimensions can vary for those vehicles using compressed natural gas, having rooftop air conditioners, or having rooftop antennae. Some multilevel roadways can not accommodate full-size buses or over-the-road coaches used by charter bus operators.
- **Competition.** Commercial vehicle operators compete with private vehicles, other operators providing the same service, and operators providing services that are perceived as being similar (e.g., taxicab and door-to-door van operators). Each commercial vehicle operator generally wishes to be assigned space nearest the busiest terminal exit doors or space that is equivalent to or near the space provided to their competitors to maintain a "level playing field."
- **Airport management policy.** Some airport operators have policies that encourage the use of public transportation and, thus, assign public transit vehicles the most convenient or most visible curb space.
- **Revenues generated by commercial vehicle operations.** Airport operators receive significant revenues from public parking and rental car concessions. As such, the courtesy vehicles serving on-airport parking lots and rental car facilities may be assigned higher priorities than other courtesy vehicles, including those serving privately operated parking or rental car facilities located off airport.

Number of Curbside Stops Made by Commercial Vehicles

An additional factor to be considered when estimating the curbside roadway lane requirements of commercial vehicles is the number of stops each vehicle makes. For example, a single courtesy vehicle or public bus may stop two or more times along a terminal curbside, depending on the length of the curb and airport policies. The calculation of curbside lane requirements for each courtesy vehicle, for example, must be adjusted to account for the number of stops.

Analytical Framework Hierarchy for Airport Curbside Roadways

Airport curbside roadway operations—particularly the reduction in through-lane capacity that results from increased curbside lane demand—can be analyzed using the quick-estimation method described below, the macroscopic method (QATAR) described in subsequent sections, or commercially available microsimulation methods used to simulate airport curbside roadways.

Quick-Estimation Method

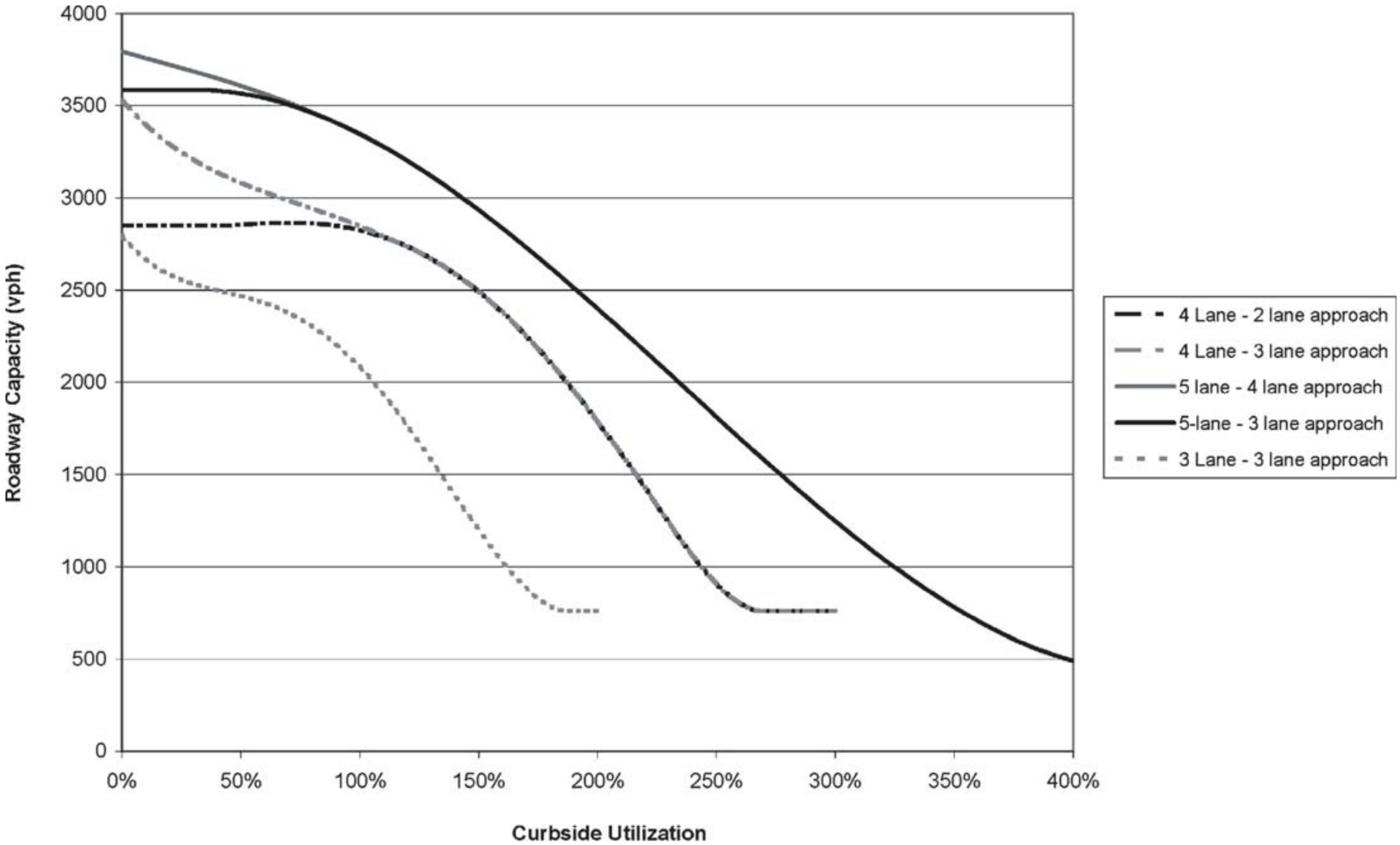
The quick-estimation method is used to measure both the curbside utilization factor (i.e., the ratio between curbside demand and curbside capacity) and the maximum throughput rate for five-, four-, and three-lane curbside roadways. The level of service for a curbside roadway is defined as the worst result of these two measures.

Estimates of the maximum flow rates (i.e., service flow rates) on curbside roadways at each level of service can be determined using the data provided in Table 5-2. These data were established from observations of curbside traffic flows conducted as part of this research project and analyses of curbside roadway traffic flows conducted using microsimulation of airport roadway traffic. Figure 5-2 depicts the relationship between curbside roadway traffic flow rates and utilization factors for five-, four- and three-lane curbside roadways.

Since as used in Table 5-2, "capacity" varies depending on whether an airport operator allows vehicles to double or single park, the policy of the airport being analyzed should be reviewed.

To establish the level of service for a given curbside demand and traffic volume, the data in Table 5-2 should be used as follows:

1. Calculate the curbside utilization factor.
2. Select the corresponding utilization factor for the curbside lane as shown in Table 5-2, rounding up to the next nearest value, and note the corresponding level of service. For example, for a four-lane curbside roadway with a calculated ratio of 0.6, the level of service is C.
3. Calculate the level of service for the through lanes by (1) selecting the maximum service flow rate row in the table corresponding to the appropriate number of lanes on the entire curbside roadway (include all curbside lanes and through lanes), and (2) comparing this rate to the volume of traffic on the curbside to calculate the volume/capacity ratio. For example, the roadway capacity is 2,680 vehicles per hour for a four-lane roadway with curbside lanes operating at LOS C. If this roadway were serving 2,500 vehicles per hour, it would have a v/c ratio of 2,500/2,680 or 0.93.



Source: Jacobs Consultancy, November 2009.

Figure 5-2. Curbside roadway capacity reduction curves.

4. Use Table 5-2 to determine the level of service that corresponds to the calculated v/c ratio for the through lanes. A v/c ratio of 0.93 corresponds to LOS E.
5. The level of service for the entire curbside roadway (system) is determined by the component—either the curbside lane or the through lanes—with the poorest level of service. Considering the above example, if the curbside utilization factor corresponds to LOS C and the peak hour traffic volume corresponds to LOS E, the level of service for the curbside roadway is LOS E.

The maximum service flow rates shown in Table 5-2 apply to all vehicles on the curbside roadway, including those stopped in the curbside lane. These flow rates need not be adjusted for heavy vehicles or driver familiarity because they were developed from observations of traffic operations on airport curbside roadways.

Macroscopic Model—Quick Analysis Tool for Airport Roadways

Developed through this research project QATAR allows airport planners and operators to determine the ability of a curbside roadway to accommodate changes in traffic volumes, airline passenger activity, vehicle mix, curbside allocation plans, and curbside enforcement levels. QATAR also allows the user to observe how airport curbside roadway levels of service are expected to vary as these input factors change. Appendix G presents additional information on the methodology and mathematics used in QATAR.

In the analysis procedure used in QATAR, it is assumed that (1) vehicles begin to double park and potentially triple park, if allowed, as the number of vehicles stopping in a zone approaches the zone's capacity (or length), and (2) the capacity of the adjacent maneuver and travel lanes decreases as the number of double- and triple-parked vehicles increases. The propensity of arriving vehicles to double park (reflecting the percentage of occupied curbside spaces) can be modified by the QATAR user to reflect local conditions and policies.

Using a multiserver (or multi-channel) queuing model, QATAR calculates

- The number of vehicles stopping in each curbside zone to drop off or pick up passengers. The number of spaces occupied simultaneously (assuming a 95% probability), when compared to the number of available spaces, defines the level of service for the curbside lane.

- The number of bypass vehicles proceeding to/from adjacent zones. The number of bypass vehicles, when compared to the capacity of the bypass lanes, defines the level of service for the bypass lanes. The capacity of the bypass lanes is determined by the number of travel lanes and the level of service of the curbside lane. As described previously, a reduction in curbside level of service (i.e., an increase in the amount of double and triple parking) causes a reduction in the capacity of the bypass lanes.
- The peaking characteristics of the roadways, assuming that the volumes will not be exceeded 95% of the time during the analysis period. Traffic volumes on curbside roadways are not uniform throughout an hour-long period, or other analysis period, and peak periods of activity or microbursts of traffic occur frequently.

Inputs

Figure 5-3 presents an example of a QATAR input sheet (including the suggested default values for dwell times and vehicle stall lengths). As shown, the following information is required to use QATAR:

- **Curbside geometry—**The physical characteristics of the curbside, including length, number of lanes, and number of roadway lanes approaching the curbside area. If the user

Quick Analysis Tool for Airport Roadways

Developed by: Jacobs Consultancy in association with Dowling Associates, Inc.

Summary of Inputs and Assumptions

Run Model

Airport	JCD Airport
Roadway location	Terminal 1
Scenario	2008 Estimates
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	6
% of 1st lane full when next vehicle double parks	80%
% of 2nd lane full when next vehicle triple parks	50%
Crosswalk adjustment factor	90%
Regional adjustment factor	95%

Frontage and dwell time per curbside operation

Vehicle class	Vehicle parking length (feet)	Average dwell time (minutes)
Private vehicles	25.0	1.6
Taxis	20.0	1.9
Limousines	30.0	5.5
Shuttle vans	30.0	2.7
Buses	50.0	3.5
Courtesy vehicles	30.0	2.8

Assumptions by zone

Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Name						
Type						
Curbside frontage (feet)	200	200	200	200	200	200
Number of lanes	4	4	4	4	4	4
Number of approach lanes	2	2	2	2	2	2
Volume of vehicles using roadway (vph)						
Private vehicles	425	425	425	425	425	425
Taxis	170	170	170	170	170	170
Limousines	85	85	85	85	85	85
Shuttle vans	85	85	85	85	85	85
Buses	43	43	43	43	43	43
Courtesy vehicles	43	43	43	43	43	43
Volume of vehicles using curbside (vph)						
Private vehicles	71	71	71	71	71	71
Taxis	28	28	28	28	28	28
Limousines	14	14	14	14	14	14
Shuttle vans	14	14	14	14	14	14
Buses	7	7	7	7	7	7
Courtesy vehicles	7	7	7	7	7	7

Figure 5-3. Example of QATAR input sheet.

wishes to divide the curbside into zones, the length of each zone must be defined first.

- **Hourly traffic volumes—**The existing hourly volume of vehicles entering the curbside. If a future curbside condition is to be analyzed, the traffic volumes should be adjusted to reflect future growth. QATAR allows the user to apply a growth factor to existing traffic volumes.
- **Through vs. curbside traffic volumes—**The proportion of vehicles using the roadway that stop at the curbside. If the user has divided the curbside into zones, the proportion (or volume) of vehicles stopping in each zone is required.
- **Vehicle mix—**The mix (i.e., classification) of vehicles in the traffic stream entering the curbside (either the actual volume or the percent of vehicles by vehicle classification). If the user has divided the curbside into zones, the proportion (or volume) of vehicles by classification stopping in each zone is required, or the user can determine that the proportion is constant in each zone.
- **Dwell times—**The user can accept the default values in QATAR or enter vehicle dwell times by vehicle classification.
- **Vehicle stall length—**The user can accept the default values in QATAR or enter vehicle stall lengths by vehicle classification.
- **Adjustment factors—**The user can enter adjustment factors in QATAR to reflect the effect of pedestrian crosswalks, regional conditions/driver behavior, and a weighting/calibration factor.

Outputs

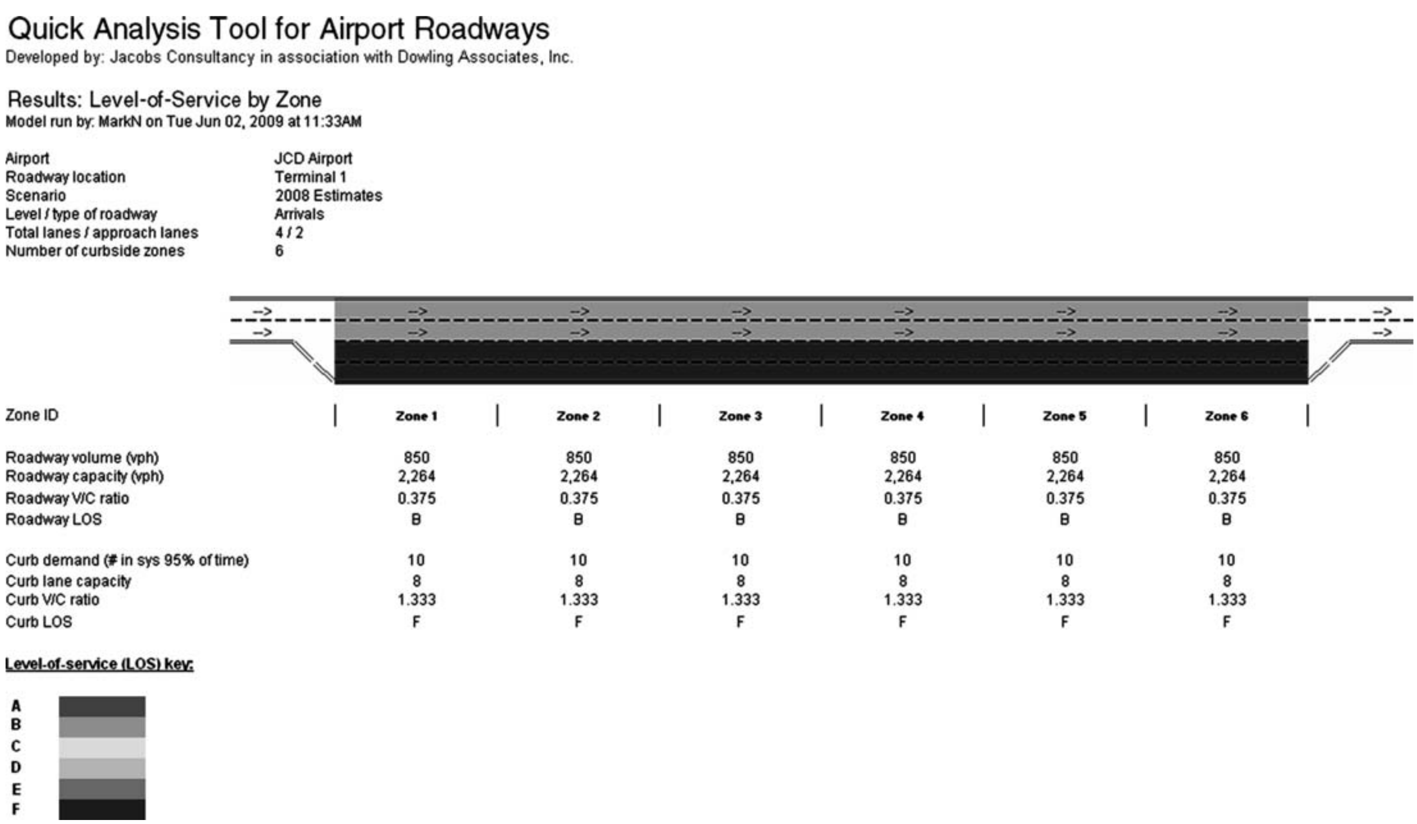
Figure 5-4 presents an example of a QATAR output sheet. As shown, QATAR yields the following outputs:

- **Level of service—**A graphic depicting the levels of service for the curbside areas and roadway through lanes in each zone.
- **Volume/capacity ratio—**A tabular presentation of the volume/capacity ratio for the through lanes in each zone.
- **Curbside utilization ratio—**A tabular presentation of the curbside utilization ratio for the curbside area in each zone.

In some cases, the capacity of the roadway approaching the curbside may dictate the capacity of the curbside roadway segment. For example, the capacity of a five-lane curbside section with a two-lane approach roadway is governed by the ability of the approach roadway to deliver vehicles to the curbside.

Limitations of the Analysis Tool

QATAR is used to analyze the macroscopic flow of vehicles but not the operation of individual vehicles (as would a roadway traffic microsimulation model). As such, QATAR does not



Quick Analysis Tool for Airport Roadways
Developed by: Jacobs Consultancy in association with Dowling Associates, Inc.

Results: Level-of-Service by Zone
Model run by: MarkN on Tue Jun 02, 2009 at 11:33AM

Airport	JCD Airport
Roadway location	Terminal 1
Scenario	2008 Estimates
Level / type of roadway	Arrivals
Total lanes / approach lanes	4 / 2
Number of curbside zones	6

Zone ID	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Roadway volume (vph)	850	850	850	850	850	850
Roadway capacity (vph)	2,264	2,264	2,264	2,264	2,264	2,264
Roadway V/C ratio	0.375	0.375	0.375	0.375	0.375	0.375
Roadway LOS	B	B	B	B	B	B
Curb demand (# in sys 95% of time)	10	10	10	10	10	10
Curb lane capacity	8	8	8	8	8	8
Curb V/C ratio	1.333	1.333	1.333	1.333	1.333	1.333
Curb LOS	F	F	F	F	F	F

Level-of-service (LOS) key:
A
B
C
D
E
F

Figure 5-4. Example of QATAR output sheet.

- Replicate or analyze operations, such as individual vehicles maneuvering into or out of curbside spaces, improperly parked vehicles, vehicle acceleration/deceleration characteristics, or how these characteristics vary by vehicle size or type.
- Analyze how roadway congestion or queues affect traffic operations in the zones located upstream of those being analyzed, or meter (i.e., restrict) the flow of vehicles into downstream zones.
- Represent pedestrians crossing a curbside roadway (properly or improperly) or vehicle delays caused by pedestrian activity other than to allow the user to estimate the approximate decrease in roadway capacity.
- Evaluate the potential capacity decreases of specific curbside geometries. Rather, a single, continuous, linear curbside roadway is assumed in the model. If the curbside roadway consists of one or more parallel curbside roadways, QATAR should be used to analyze each parallel curbside roadway separately.
- Consider any upstream or downstream congestion; rather, each zone is treated separately. In reality, a very congested section or loading zone could affect adjacent zones both upstream and downstream. The model does not capture any interaction between zones.

As such, QATAR produces an approximation of airport curbside roadway operations. If more detailed analyses are desired, the user is encouraged to use a microsimulation model capable of simulating airport curbside traffic operations.

Interpreting the Results

Certain vehicles (e.g., courtesy vehicles or door-to-door vans) may make multiple stops along the terminal curbside area, especially at large airports. Vehicles making multiple stops can be represented properly (using Option C—one of the available input sheet options in QATAR) because the total volumes of vehicles stopping in each zone need not equate to the total curbside roadway traffic. However, with Option C, QATAR requires percentages of vehicles to sum to 100% and vehicles making multiple stops may not be accurately represented, particularly if they account for a significant percentage of the total vehicles entering the roadway.

Use of Microsimulation Models

Chapter 4 provides guidance on the use of microsimulation models for analysis of airport roadways. Based on research team reviews of commercially available microsimulation software packages commonly used (as of 2008), it was determined that all are capable of adequately modeling the noncurbside terminal area roadways and low-speed weaving and merging maneuvers typically found on airports. However, not all software packages available at the time of the research team's review were capable of modeling parking maneuvers or interactions between vehicles entering and exiting curbside parking spaces and adjacent through vehicles, or permitted vehicles to double or triple park.

It is suggested that the capability of a software package be confirmed prior to considering its use in analyzing airport curbside roadway operations.

The following guidance is provided on calibrating a microsimulation model for airport curbside roadways:

- If double or triple parking is allowed, verify that the model correctly predicts the average number of double and triple parkers during the peak hour (compare one-hour model simulation to one-hour field counts).
- If queuing occurs on the existing curbside roadway, count the throughput in the through lanes and the number of vehicles processed per hour in the curbside lanes under such congested conditions.
  - Validate through-lane flow rates. Enter demands into the simulation model and verify that the maximum through-lane flow rate for the peak hour predicted by the model matches the field counts. Adjust mean headways in the model until the model through-lane volumes match the field counts. A difference of 5% to 10% between model through-lane volumes and field counts is acceptable.
  - Validate curbside processing capacity. Enter demands in the simulation model and compare the curbside processing rate to field counts. Adjust average dwell times in the model until the processing rate over the peak hour matches the field counts.

This guidance is in addition to guidance published elsewhere (see FHWA guide on microsimulation model validation).

Curbside Performance Measures for Analyses Performed Using Microsimulation

The performance measures presented in Table 5-1 are intended to help select the appropriate curbside analysis method. When curbside roadways are analyzed using microsimulation methods, the performance measures presented in Table 5-2 can be used to compare curbside roadway alternatives in the context of level of service.

The measures listed in Table 5-1 do not directly correspond to quantitative values equaling a specific level of service. For example, duration of queuing is a potentially useful measure in the context of comparing alternatives (e.g., if one curbside roadway alternative would result in 2 hours of queuing, while another would result in 1 hour of queuing), but the magnitude of the queuing itself could be relatively minor, so reporting an LOS C result for one alternative and an LOS D result for the other could be misleading. Similarly, the queue length measure can provide an easy way to compare alternatives, but a relatively long queue could be a better condition than a relatively short queue if the rate at which vehicles are served at the curbside is relatively high for the alternative with the longer queue.

Together, length of vehicle queues and average speed—two measures that are typically microsimulation software outputs—can provide a time in queue measure that can be used to compare and evaluate analyses of curbside roadway prepared using microsimulation models. Because of the wide range of motorist expectations regarding traffic conditions when they arrive at an airport curbside, a range of thresholds for time in queue between acceptable and unacceptable operations were identified, with unacceptable operations corresponding to the threshold between LOS E and LOS F. For the lowest of these thresholds, the time in queue was identified as 60 seconds. This time (60 seconds) is consistent with the LOS E/F threshold for unsignalized and signalized intersections and considered to be a reasonable lower threshold. For context, consider a small-hub airport, such as Billings Logan International Airport. Most of the time, there is no queue leading to this airport's curbside, even during peak periods in bad weather. If a queue did develop such that motorists would have to be in the queue for 60 seconds, it would seem unacceptable in that context.

For the upper bound of acceptable/unacceptable thresholds, a comment expressed in at least one focus group conducted for this research project—moving is acceptable, not moving is not acceptable—was used. From a motorist's perspective, it would seem as if a queue were not moving if a person could walk faster than the vehicles were moving. Using an arbitrary queue length of one mile and brisk walking speeds of 3 to 4 mph, the time spent in such a queue would be 20 and 15 minutes, respectively. The 20-minute time in queue appears to be a reasonable upper bound for a threshold between acceptable and unacceptable (anecdotal experience suggests that queues of this length likely occur at large airports somewhat regularly). This time in queue is not intended to represent the longest queue time during the busiest days of a year, when delays may be even greater. Also, higher values of time in queue could be used by airport operators who observe higher thresholds at their locations.

Service thresholds corresponding to LOS A have also been defined. It is suggested that time in queue should not be zero, but should seem to a motorist as if it were nearly zero. A simple way to identify an LOS A value would be to take 10% of the LOS E/F value, which is close to the LOS A/B threshold for delay at signalized intersections defined in the HCM. For the LOS E/F threshold of 60 seconds, a time in queue of 6 seconds or less would correspond to LOS A—from a practical perspective, that would essentially mean no queue or perhaps one vehicle waiting, which is consistent with the original basis for this threshold. With an LOS E/F threshold set at 20 minutes, the LOS A time in queue would, therefore, be 120 seconds. Although 120 seconds in a queue seems high compared to, for example, a signalized intersection delay, for a motorist approaching a curbside anticipating a wait of up to 20 minutes, a 2-minute wait would seem remarkably short.

Once the upper and lower level-of-service bounds are identified, the values for the other LOS values can be calculated using a straight-line projection between the two points. The results of these estimates, assumptions, and calculations are presented in Table 5-4. The information can also be presented in graph form, as shown on Figure 5-5. As noted, the values of the time in queue can easily be extrapolated upward from the 20-minute level to any value.

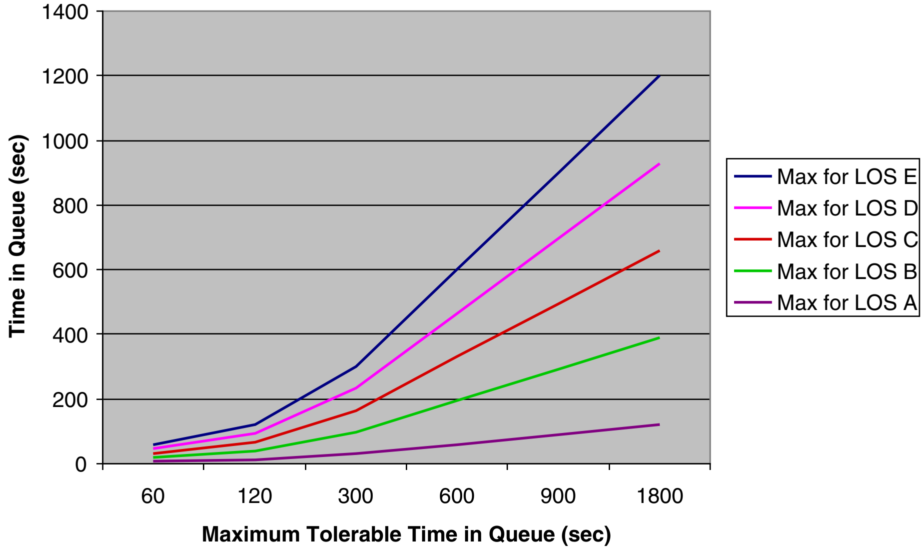
Table 5-4. Time spent in queue for levels of service.*

	Small-hub and smaller medium-hub airports (*a*)			Large medium-hub and large-hub airports (*a*)		
	Given maximum acceptable time spent in queue in seconds (*a*)					
Level of service	60	120	300	600	900	1,200
Maximum for LOS E	60	120	300	600	900	1,200
Maximum for LOS D	47	93	233	465	698	930
Maximum for LOS C	33	66	165	330	495	660
Maximum for LOS B	20	39	98	195	293	390
Maximum for LOS A	6	12	30	60	90	120

Notes:

*Input data are to be taken from microsimulation modeling output.

(*a*) Analyst must first select a value for the maximum acceptable time spent in queue for the subject airport. Then, using queue length and average speed outputs from the microsimulation model, the level of service can be identified.



Note: Analyst must first select a value for the maximum acceptable time spent in queue for the subject airport. Then, using queue length and average speed outputs from the microsimulation model, the level of service can be identified.

Figure 5-5. Time spent in queue for levels of service, large medium-hub and large-hub airports (input data to be taken from microsimulation modeling output).

CHAPTER 6

Improving Airport Curbside and Terminal Area Roadway Operations

This chapter presents examples of commonly occurring airport curbside and roadway operational problems and potential improvement measures.

Analyses and evaluations of airport curbside and terminal area roadways generally involve the following steps:

1. **Identify the Problem(s)—**Problem identification includes determining the causes of existing congestion, delays, imbalances in demand, and/or whether the existing (or proposed) roadway network can accommodate anticipated future requirements.
2. **Document Goals and Objectives—**Documenting the relevant goals and objectives of airport management (and other stakeholders) with respect to roadway operations is a key step in the analysis and evaluation process. The relevant objectives may include such broad categories as
   - Providing safe and secure operations for airport users;
   - Providing desired levels of customer service for airline passengers, visitors, employees, and other airport users;
   - Accommodating existing and future requirements;
   - Accommodating regional mobility needs/encouraging the use of public transportation;
   - Supporting regional air quality goals;
   - Supporting the airport's ability to maintain or enhance airfield capacity by ensuring that changes to roadways and curbsides do not negatively affect airfield operations or capacities; and
   - Maintaining and enhancing the net revenues generated by the airport.

   Detailed descriptions and definitions of goals will allow the development of airport-specific objectives that can be used to compare and evaluate alternative improvement measures.
3. **Identify and Develop Potential Improvements—**The potential improvement measures described in this chapter can serve as a starting point for improvements that address commonly occurring airport curbside and terminal area roadway operations. Tables 6-1 and 6-2 present commonly occurring problems and potential improvement measures for terminal area roadways and curbsides, respectively. These tables also indicate the relative benefits resulting from implementation of the improvement, although the actual benefits will vary significantly depending on the roadway configuration and nature of the problem at the specific airport.
4. **Evaluate the Potential Improvements—**The alternative analytical methods described in previous chapters can be used to quantify the changes expected to result from the potential improvements, to assess their advantages and disadvantages, and to identify the preferred improvement(s).
5. **Reach Consensus on the Preferred Improvement—**A key step in the implementation process is to build consensus supporting the selection and implementation of the preferred alternative. An evaluation process that quantifies the extent to which the potential improvement would support the stated goals and objectives of airport management (and other stakeholders) provides a foundation for achieving consensus.
6. **Implement the Preferred Solution—**This step could involve design and construction activities, operational improvements, or changes in airport management policies.

Typical Terminal Area Roadway Problems

Operational and physical problems can adversely affect the ability of terminal area roadways to accommodate traffic efficiently and safely. In this section, 10 types of deficiencies that may occur in an airport environment are identified. These deficiencies typically can result in queues or delays; many airport roadways exhibit one or more of the deficiencies described in this section.

Table 6-1. Typical terminal area roadway problems and improvement measures.

Potential Improvement Measures	Typical Problem: Insufficient roadway capacity	Insufficient merging capacity	Inadequate weaving distance	Lane imbalance	Directional information overload	Insufficient decision-making distance	Insufficient queuing space	Unexpected lane drops/ inadequate taper lengths	Unexpected transition from high-speed to low-speed roadway environment	Missing movements
1. Physical Improvements										
a. Widen roadways	●	●	◒	●	◒	◒	●	●	●	○
b. Reconfigure roadways	●	●	●	◒	◒	●	●	●	●	●
c. Improve roadway wayfinding signs	○	◒	◒	○	●	◒	○	○	○	○
d. Construct and operate traffic operations center	◒	○	○	○	●	○	○	○	○	○
2. Operational Measures										
a. Speed reduction measures	◒	◒	◒	○	○	◒	○	◒	●	○
b. Transportation demand management	◒	◒	○	○	○	○	○	○	○	○
c. Intelligent transportation systems	◒	○	○	○	●	○	◒	○	○	○
3. Airport Policies										
a. Promote transit	◒	○	○	○	○	○	○	○	○	○
b. Encourage remote terminals with express bus service	◒	○	○	○	○	○	○	○	○	○
c. Encourage consolidated courtesy shuttles	○	○	○	○	○	○	○	○	○	○
d. Manage and control commercial vehicle operations	○	○	◒	○	○	○	○	○	○	○

Note: Relative success of an improvement measure may vary significantly depending upon factors unique to an individual airport.

● Significant potential benefit ◒ Some potential improvement ○ Limited potential improvement

Table 6-2. Typical curbside roadway problems and improvement measures.

Potential Improvement Measures	Typical Problem: Insufficient curbside roadway capacity	Imbalances in demand	Insufficient number of travel lanes	Pedestrian crosswalks and pedestrian activity	Driveways serving adjacent land uses	Insufficient curb length	Inefficient allocation of curb space	Unusable curbside roadway geometry	Excessive dwell times
1. Physical Improvements									
a. Widen curbside roadways	●	●	●	◒	●	◒	◒	●	◒
b. Lengthen curbside roadways	●	●	◒	◒	●	●	●	●	◒
c. Construct additional curbside level	●	●	●	●	◒	●	●	●	◒
d. Remove pedestrian crosswalks	◒	○	◒	●	○	●	●	●	○
e. Provide alternative passenger pickup/drop-off areas	◒	◒	◒	●	◒	○	◒	○	○
2. Operational Measures									
a. Reduce curbside requirements	●	●	●	●	◒	●	●	●	●
b. Reduce the speed of curbside roadway traffic	◒	◒	○	●	◒	○	◒	○	○
c. Improve curbside enforcement	●	◒	●	●	●	●	●	◒	●
d. Revise curbside allocation	◒	●	◒	◒	◒	◒	●	●	◒
e. Modify commercial ground transportation vehicle operations	◒	●	◒	◒	◒	●	●	●	●
3. Airport Policies									
a. Rules and regulations	◒	○	○	◒	◒	○	◒	○	◒
b. Establish fees	◒	◒	○	○	○	◒	◒	○	●

Note: Relative success of an improvement measure may vary significantly depending upon factors unique to an individual airport.

● Significant potential benefit ◒ Some potential improvement ○ Limited potential improvement

Insufficient Roadway Capacity

A roadway has insufficient capacity if, during the analysis period, the roadway operates at LOS D or worse (see Chapters 4 and 5 for definitions of levels of service). LOS D refers to congested roadways and is an unacceptable basis for planning airport roadways. Specific implications of insufficient roadway capacity include (1) congested roadway sections with queues extending to upstream roadways, (2) motorists experiencing frequent congestion and significant delays, and (3) a generally unsatisfactory airport experience.

Insufficient Merging Capacity

Insufficient merging capacity results when a roadway does not provide sufficient capacity at points where two or more streams of traffic combine into a single stream. This deficiency results in roadway delays, congestion, and traffic queues extending back from the merge point. Merge segment capacity is determined by the volume of entering traffic, operating speeds, and number of lanes upstream and downstream.

Inadequate Weaving Distance

Inadequate weaving distance results when a roadway does not provide sufficient length or travel lanes to accommodate the traffic volumes at the point where two or more streams of traffic traveling in the same direction cross or merge, causing vehicles to decelerate (or stop) while waiting for adequate gaps in the traffic stream. This deficiency results in (1) vehicle delays and queues, (2) higher accident rates, and (3) slower speeds and flow rates. Factors influencing required weaving distances are operating speeds, traffic volumes (merging, weaving, and flowing through the segment), and the number of lanes that vehicles must cross to complete the desired maneuver.

Lane Imbalance

Lane imbalance results when a roadway segment, before a diverge or after a merge, contains two (or more) fewer lanes than the combined total number of lanes entering or exiting the segment. For example, at a point where two three-lane roadways merge, the downstream segment must consist of at least five lanes or a lane imbalance will result. At a point where a roadway diverges into two two-lane roadways, the upstream segment (prior to the diverge) must consist of at least three lanes. A lane imbalance can cause increased delays, sudden diverge or weave maneuvers, increases in the required roadway weaving distances (e.g., the number of lanes to be crossed), and higher accident rates. Proper lane balance helps reduce or avoid forced merges, weaves, and sudden maneuvers. For example, when a two-lane roadway splits or diverges into two roadways, lane balance can be achieved by providing a third lane prior to the diverge point that allows motorists access to either of the two downstream roadways (e.g., an "either-or" lane) or by extending a lane downstream past the merge/diverge point and then dropping the lane using design guidelines appropriate for the roadway speed (e.g., taper distances).

Directional Information Overload

Directional or wayfinding information overload occurs when more information (or decisions) is presented to a motorist than the motorist can read, comprehend, and react to in the available time (and distance). This overload causes drivers to weave suddenly, miss exits, make sudden or erroneous movements, or, in extreme cases, stop in the roadway (or on the shoulder) to read the signage.

It is desirable to avoid presenting more than two decisions or more than four lines of text on each directional sign. If more than four lines of text must be used on one sign at an airport, it is necessary to prioritize the information and avoid using unfamiliar or inconsistent terms.

Insufficient Decision-Making Distance

Insufficient decision-making distance is defined as an insufficient distance (or time) for motorists to read, comprehend, and react to information regarding a decision that must be made. This situation causes drivers to weave suddenly, miss exits, make wrong turns, or, in extreme cases, stop in the roadway to read the message or back up to the decision point. Factors contributing to providing the necessary decision-making distance include travel speed, message content, visibility of the decision point, and visibility of the directional signage.

Insufficient Queuing Space

Queuing space represents the area required to accommodate vehicles stopped at an entrance (or exit) to a parking lot or other facility, traffic signal or turn lane, or vehicle inspection area so that vehicles in the queue do not interfere with traffic flow on the adjacent roadway or travel lanes. For example, a parking facility entrance should have sufficient space to accommodate vehicles queuing at the ticket issuing machines without having the queue extend onto the adjacent roadway. (See Figure 6-1.)

Unexpected Lane Drops/Inadequate Taper Lengths

Unexpected lane drops and inadequate taper lengths (the distance required to introduce a new lane or drop an existing lane) result when a through lane unexpectedly ends and motorists are required to unexpectedly merge quickly into an adjacent lane. Required taper lengths, which vary according to

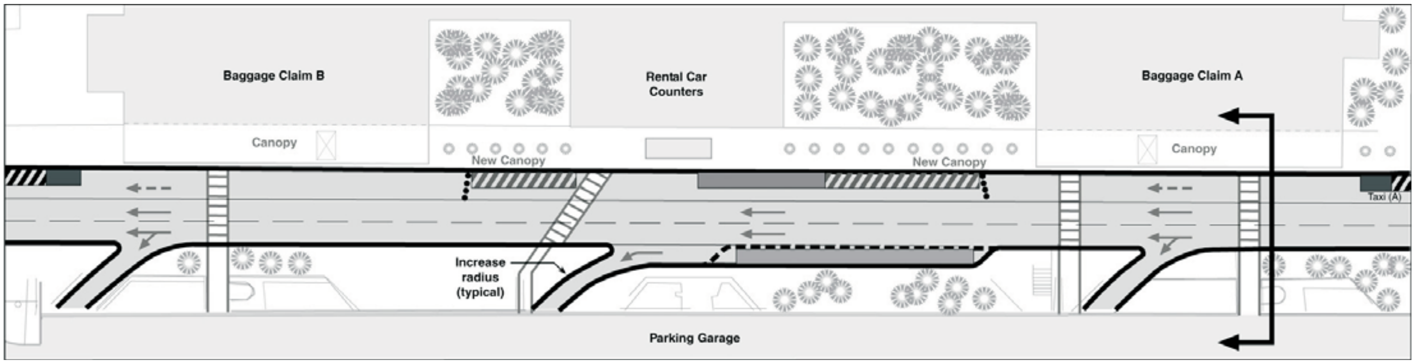


Figure 6-1. Insufficient queuing space at parking entry at Tulsa International Airport.

roadway operating speeds, are intended to allow sufficient distance for lane channelization and vehicle merging. Unexpected lane drops reduce roadway capacity and travel speeds, as motorists who become "trapped" in a lane are required to merge quickly (interfering with the flow of other vehicles in adjacent lanes).

Unexpected Transition from High-Speed to Low-Speed Roadway Environment

Some motorists do not realize they need to slow down as they exit from a regional roadway (which may operate at more than 55 mph) and approach a terminal area roadway (which may operate at less than 30 mph) until they encounter a sharp curve at the entrance to the terminal or vehicles stopped in the roadway. This situation is particularly true at airports where a limited access highway, designed to freeway standards and capable of accommodating freeway speeds, connects the regional roadway network with the terminal area roadways (see Figure 6-2). Motorists may be provided few visual clues that the driving environment is changing and requires them to decelerate. Additionally, speed limit signs may get lost among the many other signs and distractions associated with roadways approaching an airport terminal.

This transition is compounded by the reduction in roadway capacity that accompanies the reduction in speed: a three-lane access roadway operating at 55 mph (or more) has more capacity than a three-lane curbside roadway operating at 30 mph (or less). If the traffic volume on the access roadway is the same as that on the curbside roadway, it is necessary to provide additional travel lanes on the curbside roadway to compensate for the reduction in travel speed. Often, the volumes are not constant, as some traffic exits for non-terminal area destinations, such as parking and rental car facilities.

Missing Movements

Missing movements are defined as a desired travel path or traffic movement that is not provided on an airport roadway network. If a movement is missing, motorists may need to exit and re-enter the airport or travel extra distance. For example, at most major airports, motorists can proceed directly from the enplaning curbside to short-duration parking and from short-duration parking to the deplaning curbside without leaving the terminal area. The absence of roadway segments providing these direct movements increases traffic demand on the return-to-terminal roadways and vehicle miles of travel.

Potential Terminal Area Roadway Improvement Measures

Potential improvements to terminal area roadway operations are presented in the following categories:

- Physical improvements,
- Operational measures, and
- Airport policies.

Figure 6-2. Transition from high-speed to low-speed airport roadways at Baltimore/Washington International Thurgood Marshall Airport.

A general planning principle for the design and operation of airport roadways is to separate traffic generated by airline passengers and visitors from that generated by employees, air cargo, and services or deliveries. At airports with multiple entrances/exits, this can be accomplished by having one entry/exit serving airline passengers and the other serving nonpassenger traffic. At airports with one access road, this can be accomplished by having nonpassenger traffic exit the access roadway well in advance of the terminal area, and by providing a separate service roadway for these vehicles.

Appendix B (Bibliography) lists selected references regarding the design and improvement of roadways and intersections and relevant design standards and guidelines relevant to airports. These references should be reviewed prior to implementing any roadway improvement, particularly those that require the design of new roadways or modification or reconfiguration of the layout of existing roadways.

Potential Physical Improvements to Enhance Roadway Operations

Widen Roadways

Additional roadway capacity can result from the following:

- **Constructing new lane(s).** Additional lanes can be constructed if sufficient available right of way is clear (or if it can be cleared) of obstacles, such as existing or proposed buildings, underground utilities, aviation limit lines (where FAA restrictions govern acceptable land uses), or other fixed obstacles. Construction costs and schedules are a function of the roadway alignment, extent and type of construction, obstacles to be relocated (if any), need to maintain and protect other vehicular and pedestrian traffic during construction, and other factors.
- **Reconfiguring existing lanes.** Additional lanes can be created by reducing the widths of existing roadway lanes to form additional lanes. For example, five lanes can be created on an existing four-lane roadway by reducing lane widths (e.g., from 13 feet or 12 feet to 11 feet or 10 feet) and by simultaneously reducing the width of, or converting, roadway shoulders or paved gutter strips into travel lanes. Unless existing drainage structures must be replaced or relocated, the cost of such reconfiguration is very low.
- **Lengthening tapers/correcting lane imbalances.** Roadway construction is required to correct inadequate roadway tapers or lane imbalances. The length of a roadway taper depends on the posted speed. For example, a 250-foot-long taper is required on a 35 mph roadway to add (or end) a 12-foot-wide travel lane. Providing the required lane balance may require construction of a full lane (upstream or downstream) for a longer distance. Highway design guides listed in Appendix B, including those published by AASHTO, provide additional information on this topic.
- **Adding exclusive left- or right-turn lanes.** The capacity of at-grade intersections, particularly signalized intersections, can be improved by providing exclusive left-turn lanes (thereby eliminating conflicting traffic movements from a signal phase) or adding free-flow right-turn lanes.

Reconfigure Roadways

- **Eliminating three-way decision points.** It may be possible to eliminate a three-way decision point without requiring major roadway reconstruction, by moving one of the decision points upstream and thereby converting the three-way decision point into two separate two-way decision points, which is preferable and easier for motorists.
- **Lengthening weaving area.** It may be possible to improve an unacceptable weaving operation by closing one exit from the weaving area and directing traffic to a subsequent downstream exit leading to the same destination. For example, at Seattle-Tacoma International Airport, traffic operations on a return-to-terminal roadway were improved by directing recirculating traffic toward the airport exit and then to a path that leads back to the terminal, thereby extending the length of the weaving area. At Los Angeles International Airport, a movable gate arm is used to close a roadway to traffic on the busiest days of the year, requiring vehicles to follow a slightly longer path, but extending the length of the weaving area. Such improvements can be implemented for minimal cost (e.g., replacing a roadway directional sign and installing a barrier, if necessary).
- **Improving queuing space.** Queuing space can be improved by either providing additional storage space or increasing flow rates through the point of constraint. For example at the entry or exit of a parking facility, queuing space can be increased (1) by relocating the gate arms at the entry or control booths at the exit plaza to provide additional storage space or (2) by increasing traffic flow rates at the control point by replacing the existing access control technology (e.g., replacing an existing ticket issuing machine with a card reader recognizing employee parking badges, or an automatic vehicle identification [AVI] transponder on commercial ground transportation vehicles). For example, with use of a credit card in/credit card out parking access control system, more vehicles can be processed per lane than with a cashier, and the need to print and issue parking tickets may be reduced or potentially eliminated.

Improve Roadway Wayfinding Signs

It may be possible to improve roadway guide signs by replacing complex, existing signs with simpler signs that can be more easily understood by motorists. This can be accomplished by attempting to simplify and prioritize the message content, reviewing the text and font, and using standard phraseology where possible. The use of dynamic message signs may also be helpful in certain instances (e.g., parking controls and space availability).

Construct and Operate Traffic Operations Center

At airports with complex roadway networks and multiple parking facilities, it may be possible to improve traffic flows by constructing and operating a traffic operations center, similar to those in many large urban areas (see Figure 6-3). Using video cameras, traffic detectors, and other technologies, the traffic operations center allows airport staff to monitor airportwide traffic operations, direct airport traffic officers to congestion points, close or open parking facilities or roadways, change advisory signs, and perform other operations to improve the flow of traffic.

Potential Operational Measures to Enhance Roadway Operations

Speed Reduction Measures

It may be necessary to encourage motorists to decelerate as they approach the terminal area, particularly at airports where a limited access highway connects the regional roadway network with the terminal area roadways.

Measures to encourage motorists to obey posted speed limits and slow down as they approach the terminal area include

- **Pavement texture.** Contrasting pavement textures (e.g., brick, cobblestone, or gravel textures) can be cast into strips of concrete pavement to create a warning signal (i.e., a rumble strip) for motorists as they approach a slow-speed area. It is possible to increase the frequency and volume of the warning signal by reducing the distance between successive strips.
- **Dynamic warning signs.** Radar-activated speed limit signs can be installed to detect the speed of approaching vehicles and indicate to drivers how fast they are traveling. For vehicles exceeding the posted speed limit, the display could flash red.
- **Automatically activated pedestrian signals.** Pedestrians crossing a roadway can automatically activate signals embedded in the roadway pavement.
- **Enforcement.** Police enforcement measures and tools that are commonly and frequently used in non-airport environments can be used to enforce posted speeds, including parking police vehicles in a visible location.

Figure 6-3. Transportation operations center at Frankfurt Airport.

Transportation Demand Management

When used in an urban or regional setting, transportation demand management (TDM) measures are used to discourage single-occupant, private vehicle trips by promoting ridesharing or the use of public transit, and to encourage motorists to drive outside peak hours. At airports, the most productive application of TDM is to encourage airport employees to share rides or use public transit to reduce the number of vehicle trips. For example, some airport operators and other employers have established work schedules that call for employees to work 9 out of every 10 days (e.g., take every other Friday off by working longer hours on other days). Other airport operators offer discounted transit passes or partially subsidize the commuting expenses of employees who agree to use transit and forego the use of parking facilities.

Intelligent Transportation Systems

A variety of intelligent transportation system (ITS) applications are available to encourage the efficient and safe use of transportation facilities. At airports these applications include pricing mechanisms (increasing parking costs), the use of AVI and global positioning system (GPS) technologies to monitor the location and number of trips made by commercial vehicles or shuttle buses, and a variety of systems for distributing traveler information to arriving motorists (e.g., airline schedules/delays and parking space availability). Traveler information can be distributed using the Internet, mobile telephones, highway advisory radios, flight information display systems (e.g., those located on deplaning curbsides or within cell phone lots), or dynamic signage presenting parking space availability information or warning overheight vehicles approaching areas with limited vertical clearance.

Potential Airport Policies to Enhance Roadway Operations

Promote Transit

Airport operators generally encourage the use of public transportation by supporting the construction and operation of rail transit services and by promoting the use of rubber-tired public transit services. Specific actions used by airport operators to promote passenger (and employee) use of bus service include allocating the most convenient terminal curb space for bus stops, installing signs indicating bus schedules and expected waiting times, installing transit ticket vending machines at visible locations in the terminal building, providing employees with a guaranteed ride home in the event of emergencies, and subsidizing selected modes to reduce the cost to passengers.

Encourage Remote Terminals with Express Bus Service

An example of a remote terminal is an intercept parking lot that provides scheduled, express bus service for airport passengers and employees to and from the airport terminal. By encouraging the use of efficient access modes, these terminals reduce the number of vehicle trips on airport roadways. The operators of the airports serving Boston and Los Angeles subsidize remote terminals and express bus services (e.g., the Logan Express and Los Angeles Flyaway services) and similar privately operated services are provided at Kennedy, Newark Liberty, and San Francisco International Airports and LaGuardia Airport. (See Appendix B for additional information.)

Encourage Consolidated Rental Car Buses or Courtesy Shuttles

Consolidated rental car shuttle buses used at airports that have consolidated rental car centers replace the courtesy vehicles operated by individual rental car companies and thereby reduce the number of vehicle trips on airport roadways. The consolidated rental car shuttle buses can be operated by a rental car industry consortium or by the airport operator (using a third-party contractor) on behalf of the rental car companies. Some airport operators have successfully encouraged hotels/motels to operate consolidated courtesy vehicles or shuttle buses.

Manage and Control Commercial Vehicle Operations

Numerous measures are available to manage and control commercial ground transportation vehicle operations. These measures, which primarily affect curbside roadway operations, but may also improve other roadway operations, are described in the remainder of this chapter.

Typical Curbside Roadway Problems

Operational and physical problems can adversely affect the ability of airport curbside roadways to accommodate traffic safely and efficiently. Typical problems include those listed in this section.

Insufficient Curbside Roadway Capacity

Insufficient curbside roadway capacity exists when curbside requirements (lengths) are greater than 1.3 times the usable curbside length and/or the through lanes on a curbside roadway operate at LOS C or worse. When curbside demand exceeds available capacity, motorists experience significant delays and queues, as evidenced by high levels of double and triple parking throughout the entire curbside, which, in turn, reduces the capacity and travel speeds of the curbside roadway through lanes. As noted previously, curbside roadways must provide both adequate curbside length (stopping space) as well as adequate throughput capacities. Any deficiencies in one area will adversely affect the other. Factors that contribute to a lack of curbside roadway capacity are described in the following paragraphs.

Imbalances in Demand

Imbalances in curbside demand occur when the total length of curbside space available is sufficient to accommodate curbside demand, but most of the demand occurs at, and overloads the capacity of, one segment of the total curbside area. For example, if one or more airlines on one concourse serve most of the peak-hour airline passenger activity, then curbside traffic will be concentrated at the doors leading to the portions of the terminal building occupied by these airlines, leaving the remainder of the curbside areas empty or underutilized. Generally, it is not feasible to relocate the assigned airline ticket counter or baggage claim area locations solely to balance curbside demand.

Insufficient Number of Travel Lanes

A curbside roadway that does not provide sufficient capacity to accommodate existing or future requirements at LOS C or better typically has an insufficient number of travel lanes. Generally, curbside roadways with four lanes or more provide sufficient capacity because two travel lanes remain available even when double parking occurs. Congestion and delays may occur frequently on curbside roadways having three lanes or fewer as any double parking severely restricts through traffic. Similar restrictions also occur when vehicles are allowed to stop on the inner and outer lanes of a four-lane curbside, leaving only the two center lanes for through traffic.

Pedestrian Crosswalks and Pedestrian Activity

Pedestrians crossing a curbside roadway restrict the volumes of through traffic that can be accommodated. Delays caused by crosswalks are related to the volume of pedestrians walking across a curbside roadway, the proportion of time that pedestrians occupy a crosswalk (properly or improperly), and the number of crosswalks located at curbside. Traffic flows and safety also can be adversely affected by pedestrians stepping into the roadway to avoid columns or other obstacles, hail vehicles, or board/alight from a vehicle stopped in a through lane.

Driveways Serving Adjacent Land Uses

Driveways serving adjacent land uses (e.g., parking lots or rental car ready/return areas) may impede the flow of curbside traffic when vehicles in the lane farthest from the terminal decelerate (or accelerate) as they enter (or exit) the driveways serving the adjacent land uses. Vehicle queues formed at the entrances to these land uses may extend back onto the curbside roadways.

Insufficient Curb Length

Insufficient curb lengths result from curbside demand that is greater than 1.3 times the usable curbside length, which also occurs when there is significant double parking.

Inefficient Allocation of Curb Space

Inefficient allocation of curb space results where the total available space is adequate to accommodate demand, but the available space has been divided into (or allocated among) many categories of ground transportation services such that some categories are allocated more curb space than required while others are not allocated enough. This situation may occur when curb space is allocated to vehicles that rarely serve the airport (e.g., charter buses), demands have changed as a result of the introduction of new services, or the space has been broken into small segments that do not correspond to the operational or maneuverability needs of the assigned class of ground transportation service.

Similarly, inefficient allocation of curb space results when the amount of curb associated with a specific airline does not match the relative share of passenger traffic served by that airline.

Unusable Curbside Roadway Geometry

Unusable curbside roadway geometries exist when vehicles cannot stop to load or unload passengers because of the curved alignment of the roadway, narrow sidewalks, or other physical obstructions. Many terminals have curved curbside roadways, but generally the radii of these roads are very large and motorists do not perceive that they have stopped along a curvilinear section. However, some curbside roadways have small radii or tight curves that hinder a motorist's ability to park parallel to the sidewalk or to enter or exit this space. Motorists may be unable to park adjacent to curbsides having narrow sidewalks (e.g., the ends of island curbside areas) or columns (or other obstacles) adjacent to the roadways. Large bollards, which are sometimes placed on terminal building sidewalks to protect pedestrians and the terminal building from vehicles that may accidentally jump the curb, may interfere with the ability of motorists to open/close their doors or enter/exit their vehicles.

Narrow sidewalks also may force pedestrians to step into the roadway (with their baggage) to bypass columns, queues of passengers formed at skycap positions, benches, or other obstacles.

Excessive Dwell Times

Excessive dwell times result when vehicles (either private or commercial) are allowed to remain at the curbside when not actively loading or unloading passengers. In the case of some commercial vehicle providers, excessive dwell times are permitted by airport rules and regulations. Excessive dwell times may reflect insufficient police presence or visibility, or permissive airport policies and may occur even if the dwell times of most vehicles are within reasonable limits and fewer than 10% of vehicles remain at the curbside for excessive periods.

Potential Curbside Roadway Improvement Measures

Potential curbside roadway improvements to enhance operations are presented for the following categories:

- Physical improvements,
- Operational measures, and
- Policy measures.

Physical Improvements to Enhance Curbside Operations

Widen Curbside Roadways

Additional curbside roadway capacity can be provided by the following:

- **Adding lanes to an existing curbside roadway.** Widening a roadway from four lanes to five lanes, for example, can increase through-lane capacity and allow the roadway to better accommodate double- or triple-parked vehicles as well as the interruption to through traffic caused by vehicles entering and exiting curbside lanes.
- **Constructing new curbside roadway(s) and center island curbside area.** Constructing a second (or third) roadway parallel to an existing curbside roadway can increase (almost double) the capacity of a curbside area. The amount of additional capacity realized from such an improvement is a function of the resulting effective length and the allocation of space. Private vehicle motorists are reluctant to use curbsides perceived as being less convenient. Customer service and the attractiveness of a curbside waiting area can be enhanced by providing weather protection for passengers at curbside areas not located immediately adjacent to a terminal building or under a building canopy. Similarly, shelters with benches can improve the service levels for customers waiting for scheduled transportation services or courtesy vehicles.
- **Constructing a new bypass roadway.** At airports with multiple terminals, construction of a bypass roadway can reduce the volume of through traffic on a curbside roadway and increase the level of service.

Lengthen Curbside Roadway

It may be possible to extend the length of a curbside area past the terminal building façade if conveniently located doorways are available to serve motorists using these extensions. Commercial vehicles can be assigned to extended curbside areas, particularly infrequent users of the airport, such as charter vehicles. Private vehicle motorists prefer to stop in front of the terminal building and are unlikely to use extended curbside areas unless they are perceived as convenient.

Construct Additional Curbside Level

At airports with a single-level curbside roadway serving a multilevel terminal building, additional capacity can be provided by constructing a new elevated curbside roadway. For example, in 1984, a second-level curbside roadway was constructed above the then single-level curbside roadway at Los Angeles International Airport. A second-level curbside roadway also was added at Hartford's Bradley International Airport. Such a capacity enhancement requires that the terminal building either have multiple levels or be modified concurrently with the roadway expansion.

Generally, it is considered impractical to add capacity by constructing a two-level curbside to serve a single-level building or a three-level curbside to serve a two-level terminal building because passenger terminal building layouts dictate curbside roadway designs (rather than vice versa). A roadway that does not match a building's floor elevation would require separate vertical circulation elements to allow passengers to transition between the terminal building and roadway. Consequently, the decision to construct a second-level curbside roadway, for example, is driven by the design of a new terminal building or planned expansion of an existing terminal building.

Remove Pedestrian Crosswalks

Additional capacity can result from the following:

- **Merging crosswalks.** Roadway traffic operations can be improved by merging crosswalks to reduce the number of locations where vehicular traffic flow is interrupted. Such changes may reduce the level of service for some pedestrians, because they would be required to walk farther. In the extreme case, it may be necessary to install fences or barriers to discourage jaywalking, and potentially to use traffic signals or traffic control officers to control pedestrian traffic.
- **Relocating pedestrian traffic.** Roadway traffic operations can be improved and pedestrian levels of safety enhanced by constructing pedestrian bridges above, or tunnels beneath, a curbside roadway and removing at-grade pedestrian crosswalks (see Figure 6-4). Since the path would require pedestrians to change grades (while transporting baggage), it would be necessary to make the new path more attractive than an alternative at-grade path, or to construct fences or other barriers to discourage passengers from continuing to cross the curbside roadway at grade.
- **Controlling pedestrian activity.** Pedestrians crossing a roadway can automatically activate signals embedded in

Figure 6-4. Elevated pedestrian bridge at Los Angeles International Airport.

the roadway pavement to improve pedestrian safety and control pedestrian and vehicular traffic flows.

Provide Alternative Passenger Pickup/Drop-Off Areas

Alternative or supplemental curb space can be developed to augment the capacity of the areas adjacent to the terminal building. Examples of alternative passenger pickup or drop-off areas include

- **Curb space within a parking garage.** Several airports have curbside areas within parking garages allocated for commercial ground transportation or private vehicles, or space adjacent to the garage that is not directly accessible from a terminal building. These areas are particularly attractive when grade-separated pedestrian access is provided between the terminal and the parking structure. Examples include
  - A curbside roadway located within a garage allocated to commercial vehicles (e.g., Seattle-Tacoma International Airport);
  - A commercial vehicle passenger pickup area/curbside space located at a close-in parking structure away from the terminal (e.g., Indianapolis International Airport); and
  - A curbside roadway located within a parking garage allocated to private vehicles (e.g., Lambert-St. Louis International, Salt Lake City International, and LaGuardia) (see Figure 6-5).
- **Commercial vehicle courtyards.** A commercial vehicle courtyard is a parking area adjacent to or near the terminal building reserved for use by commercial vehicles picking up or dropping off airline passengers. These areas are referred to by various terms, such as "ground transportation center" or "intermodal center." Courtyards and dedicated curbside roadways can augment the capacity of a curbside area (or relieve congestion) by providing additional passenger pickup (or drop-off) areas. These areas can benefit commercial vehicle operations as the operators need not maneuver through private vehicle traffic to enter and exit their assigned spaces, and are allowed longer dwell times in these areas. Commercial vehicle courtyards are provided at the airports serving Atlanta, Fort Lauderdale, Newark, San Francisco, and Tampa. The airports serving Denver, Nashville, Orlando, San Francisco, Toronto, and Washington, D.C. (Dulles) have three-level curbside areas (see Figure 6-6) with one entire level reserved for commercial vehicle use. Although these commercial vehicle areas operate in a manner similar to courtyards, they are not considered potential curbside improvement measures because, as noted earlier, their implementation requires the appropriate terminal building configuration.
- **Remote curbsides.** At Chicago O'Hare International Airport, commercial vehicles pick up and drop off passengers on a roadway located between the on-airport hotel and the central parking garage. Underground tunnels link this site (the Transportation Center) to the terminal buildings. An enclosed and heated/air conditioned passenger waiting area with seating is provided in the parking garage adjacent to the Transportation Center. At San Francisco International Airport, a supplemental remote curbside is available to serve the drivers of private vehicles meeting arriving passengers. This supplemental curbside is located adjacent to a remotely located Consolidated Rental Car Facility and automated people mover station. The station, intended primarily for use by rental car customers, allows passengers to easily travel to the supplemental remote curbside.

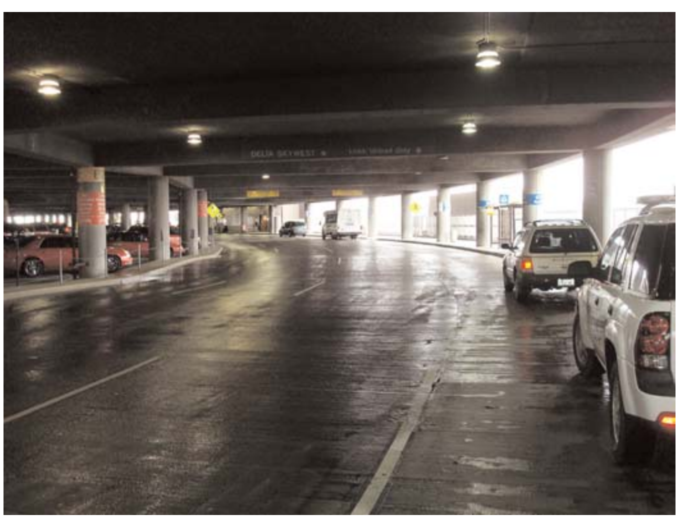


Figure 6-5. Supplemental curbside inside parking structure at Salt Lake City International Airport.

Figure 6-6. Three-level curbside at San Francisco International Airport.

Operational Measures to Enhance Curbside Capacity

Reduce Curbside Requirements

The following measures are intended to enhance curbside capacity for certain vehicle modes by reducing the amount of curbside required by other vehicles.

- **Restrict curbside use to authorized vehicles.** The use of curbside areas (or portions of curbside areas) can be restricted to authorized commercial ground transportation vehicles. Numerous airport operators limit the use of commercial vehicle lanes by posting "authorized vehicles only" signs at the entrance to these lanes, or by installing gate arms activated by AVI transponders, proximity cards, or other devices. Unauthorized commercial vehicles (e.g., those without airport permits or AVI tags) cannot gain access to these areas. As noted in subsequent paragraphs, commercial vehicles may be required to abide by other airport regulations limiting their use of curbside roadway areas.
- **Develop cell phone lot.** A cell phone lot (also referred to as a park and call lot) is a free parking area located away from the terminal where a motorist picking up a deplaning passenger can wait until the passenger has gotten off the plane, claimed baggage, arrived at the curbside, and called the motorist to indicate their arrival at the curb. Cell phone lots enable motorists to use curbside areas efficiently because (1) the airline passengers can tell the drivers exactly where they are (or will be) located at the curb, (2) if the curbside area is congested, the passenger and motorist can arrange an alternate pickup location (e.g., a different curbside area), and (3) the motorist will avoid being forced to leave the terminal area and possibly recirculate multiple times (e.g., if the airline passenger was not ready when the motorist first arrived at the curbside). The operators of some airports (e.g., those serving Phoenix and Salt Lake City) have placed outdoor flight information display monitors or dynamic signs presenting this information within cell phone lots to assist waiting drivers (see Figure 6-7). At other airports (e.g., Tampa International Airport), such signs have been installed on the deplaning level curbside to aid waiting motorists and encourage them to exit the curbside when flights are delayed (see Figure 6-8). Several airport operators have or are developing on-airport convenience stores or retail centers where the parking area can be used as a cell phone lot (e.g., Denver International Airport).
- **Provide attractive or free short-term parking.** Motorists can be encouraged to park in a conveniently located short-term parking lot if they are confident that they can easily find an empty, reasonably priced space. Encouraging motorists to park while accompanying an airline passenger to/from the terminal rather than using the curbside areas reduces curbside requirements. The extent of the reduced demand is a function of the proportion of motorists attracted to parking who would not have otherwise parked. To encourage the use of short-term parking, some airport operators offer free parking for up to 30 minutes. However, analyses of before-and-after data at Seattle-Tacoma International Airport indicate that 30 minutes of free parking had a negligible effect on curbside requirements.
- **Encourage the use of public transit.** As described in the previous section on Potential Airport Policies to Enhance Roadway Operations, by encouraging airline passengers to use public transit, airport operators can reduce airport roadway and curbside traffic. Numerous methods are available to encourage the use of public transit, including allocating preferential curb space to publicly or privately operated public transit services.

Figure 6-7. Flight information display system at cell phone lot at Salt Lake City International Airport.

Figure 6-8. Flight information display system at deplaning curbside at Tampa International Airport.

Reduce the Speed of Curbside Roadway Traffic

Measures to encourage motorists on curbside roadways to operate safely or to slow down and watch for pedestrians crossing the roadway include the following (in addition to those described above under roadway operations):

- **Use speed humps and speed platforms or tables.** These devices are forms of raised roadway pavements placed across a travel lane to force motorists to slow down. These devices are generally used on roadways operating at less than 25 mph. The key differences between these devices are their length and the amount of speed reduction achieved. Speed humps are 6 to 12 inches high, and about 4 to 6 feet long with a gradual sloping approach. Speed platforms or tables are flat-topped speed humps that are long enough for an entire vehicle to rest on top, and that can function as raised pedestrian crosswalks. Speed platforms can reduce traffic speeds, help indicate the locations of crosswalks to motorists, and minimize grade changes for disabled pedestrians crossing the curbside roadway. It is necessary to confirm that adequate vertical clearance will be possible prior to installing a speed hump or platform on the lower level(s) of a multilevel roadway. The use of speed bumps—raised devices 2 feet long or shorter with abrupt slopes—is strongly discouraged.
- **Roadway width restrictions.** Narrower lanes or physical constraints on roadway widths can encourage motorists to drive slowly. Curbside roadway widths can be constrained by reducing the number of roadway lanes, or lane widths at crosswalks, the ends of median islands, and other locations.

Improve Curbside Enforcement

Police enforcement procedures commonly used elsewhere can be used to enforce curbside traffic operations at airports. Enforcement of dwell times and unattended vehicle prohibitions typically receive more attention than speeding on curbside roadways. Some airport operators contract with a tow truck operator parked at, or near, the curbside entrance to discourage motorists from leaving their vehicles unattended, remaining at the curbsides too long, or engaging in other improper behavior.

Some airport operators employ traffic control officers (TCOs) rather than licensed law enforcement officers (LEOs) for curbside operations because of their effectiveness (TCOs can focus entirely on traffic control and are not dispatched to other assignments) and cost (TCO wages are typically lower than those of LEOs); thus, an airport operator can hire more TCOs than LEOs.

Revise Curbside Allocation

The space allocated for individual categories of ground transportation services can be revised by

- **Modifying the amount of space allocated.** The amount of space allocated to each category of ground transportation service (including private vehicles) can be increased or decreased to respond to changes in airline passenger activity or curbside requirements, introduction of new transportation services, or new airport policies.
- **Moving assigned spaces.** The assigned space can be relocated to a better (or worse) location near a major exit door serving a major airline or to an inner curbside from an outer curbside.
- **Combining or separating spaces.** The curb space allocated to different categories of ground transportation can be merged or separated. For example, all courtesy vehicles can be required to use a common curbside area rather than separate space being allocated for the courtesy vehicles serving hotels, parking lots, and rental car companies (or these services can be separated).
- **Requiring single-stop operations.** Improved utilization of available curb space can result from requiring commercial vehicle operators to drop off and pick up passengers at the same location (e.g., having courtesy vehicles drop off and pick up their customers on the upper level). This requirement reduces the number of stops and amount of spaces required by these vehicles. Requiring commercial vehicles or public transit to drop off and pick up customers at a single location also reduces customer service by requiring more level changes and longer walks.
- **Using off-peak areas.** Improved utilization of existing curb space can result from requiring commercial vehicle operators to drop off and pick up passengers at underutilized areas of the terminal building. An example would be requiring commercial vehicles to drop off customers at the baggage claim area during the enplaning peak hour or to pick up passengers at the ticketing area during the deplaning peak hour.

Modify Commercial Ground Transportation Vehicle Operations

Airport operators can establish ground transportation rules and regulations that govern how, where, and when a ground transportation vehicle operator is allowed to use airport roadways. The following section provides additional information.

Potential Airport Policies to Improve Curbside Operations

Airport operators can require commercial vehicle operators picking up airline passengers to abide by airport rules and regulations governing (1) the roadways each operator may use, (2) where commercial vehicle operators are allowed to stop on the airport roadways to drop off or pick up passengers, (3) the maximum dwell times permitted, (4) the speed limits and other restrictions they must obey, and (5) the fees they must pay to operate on the airport. Examples of these policies and regulations are provided below.

Airport operators may require the operators of commercial ground transportation services to pay a variety of fees to recover costs or manage demand. These fees include those charged on an annual or monthly basis per company or per vehicle, and cost-recovery fees typically calculated based on the ground transportation operator's volume of vehicle trips or volume of airport-related business. Demand management fees include fees penalizing operators that remain in the curbside area in excess of a specified maximum dwell time, exceed a daily or monthly limit on the number of courtesy vehicle trips, and violate established minimum time intervals between successive courtesy vehicles they control. Airport operators may use these fees to improve curbside traffic operations, discourage unnecessary trips—including those made by an operator seeking to advertise its product or service (i.e., operating moving billboards rather than transporting customers)—reduce vehicle emissions and improve air quality by encouraging the use of alternative fuel vehicles or consolidated shuttle vehicles through the use of discounted fees, or achieve other objectives of the airport operator.

Appendices

Appendix A, Glossary, is provided herein, and Appendices B through G, as submitted by the research agency, are available at www.TRB.org. Their titles are as follows:

Appendix B	Bibliography
Appendix C	Summary of Terminal Area Roadway Traffic Volume Surveys
Appendix D	Summary of Curbside Roadway Characteristic Surveys
Appendix E	Summary of Focus Group Surveys
Appendix F	A Reproduction of Portions of TRB Circular 212
Appendix G	Overview of QATAR Curbside Analysis Methodology

APPENDIX A

Glossary

Adjusted flow rates—The maximum rate of flow adjusted for traffic conditions, traffic composition, roadway geometry, and other factors.

Air taxi—A for-hire passenger or cargo aircraft that operates on an unscheduled basis.

Airfield licenses—Licenses or permits required to operate a ground transportation vehicle on an airfield at major airports.

Airport curbside—The one-way roadway located immediately in front of the terminal building where vehicles stop to pick up and drop off airline passengers and their baggage.

Automatic traffic recorder (ATR)—Equipment, often portable, that records the volumes of traffic crossing a pneumatic tube or detector.

Automatic vehicle identification (AVI)—Radio frequency identification equipment (i.e., vehicle-mounted tags or transponders) commonly used on roadways and bridges to collect tolls.

Auxiliary lane—A supplementary lane intended to facilitate weaving or merging vehicle movements between a roadway entry and exit.

Bypass lanes—Curbside roadway lanes intended for use by vehicles bypassing or not stopping at a curbside section or zone.

Bypass vehicles—Vehicles traveling past, but not stopping at, a curbside section or zone, including vehicles recirculating past the curbside, vehicles traveling to/from adjacent curbside zones, or service/delivery vehicles using the curbside roadway.

Cell phone lots—Free parking lots, typically located away from the terminal area, provided for use by motorists waiting to pick up deplaned passengers. Also referred to as "call-and-wait" or "park-and-call" lots.

Commercial vehicles—Vehicles transporting airline passengers and visitors, including taxicabs, limousines, courtesy vehicles, buses, and vans, driven by professional drivers for which vehicle passengers pay a fee or for which the transportation is incidental to the service provided (e.g., a hotel courtesy vehicle).

Cost path—A person's perceived cost that would be incurred while traveling along a defined path or route, typically including the value of time.

Courtesy vehicles—Door-to-door, shared-ride transportation provided by the operators of hotels/motels, rental car companies, parking lots, and other services solely for their customers.

Critical movement analysis—An analysis conducted to calculate the lanes or movements requiring the most "green time" at a signalized intersection and, therefore, a method of estimating the intersection volume to capacity (v/c) ratio.

Critical volumes—The volume or combination of volumes (e.g., conflicting movements) that produces the highest demand for an intersection lane or signal phase.

Curbside geometry—The horizontal and vertical alignment features of a curbside roadway, including lane widths, grades, curvature, and crosswalks.

Customs and Border Protection (CPB)—The U.S. government agency responsible for, among other duties, inspection of international arriving passengers and goods to collect import duties and prevent the import of illegal goods.

Decision-making distance—The physical distance between successive decision points.

Decision point—The physical location where a driver must select between alternative paths or roadways.

Deplaned passengers—Passengers that alighted from an aircraft at an airport, including both connecting and terminating airline passengers.

Discount factor—An adjustment applied to reduce the effective capacity of curbsides with an unusual configuration, location, or operation.

Double parking—A condition in which two or more vehicles are parallel parked or stopped adjacent to one another along the curbside roadway.

Driver population factor—A factor applied to roadway capacities to reflect driver behavior and operating characteristics, including familiarity with roadways, intersections, and traffic patterns.

Electronic ticketing kiosk—A self-serve machine used by airline passengers to print boarding passes and other documents.

Enplaned passengers—Passengers who boarded an aircraft at an airport, including both connecting and originating airline passengers.

Fixed-base operator (FBO)—An aviation business that serves general aviation aircraft owners and operators, including fueling, catering, aircraft maintenance, and storage.

Flattening the peak—A reduction in the proportion of demand occurring in a 15-minute or hourly interval as a result of demand management, changes in schedules, demand approaching capacity, or other reasons.

Free-flow speed—The mean speed of traffic under very light flow conditions.

General aviation—All flights (or aircraft operations) other than scheduled/commercial or military flights.

Gore—The triangular area between two roadways at the point they diverge or merge.

Green time—The duration, in seconds, of the green indication for a given movement at a signalized intersection.

Growth factor—A factor applied to passenger or traffic volumes, for example, to adjust for anticipated future growth.

Heavy vehicle—A vehicle with more than four wheels touching the pavement during normal operation.

Heavy vehicle factor—A factor applied to roadway capacities to reflect the proportion of heavy vehicles in the traffic stream.

Highway capacity analysis procedures—Analytical procedures conducted using the procedures described in the *Highway Capacity Manual.*

***Highway Capacity Manual* (HCM)**—The *Highway Capacity Manual* published by the Transportation Research Board, National Research Council, 2000 (and subsequent editions, including the draft 2010 HCM).

Immigration and Customs Enforcement (ICE)—The U.S. government agency responsible for, among other duties, inspection of international arriving passengers and crew prior to their entering the country.

Intelligent transportation system (ITS)—Information and communication technologies applied to transportation infrastructure and vehicles to improve operations, safety, and efficiency.

Intersection Capacity Utilization (ICU) method—As used in this Guide, a quick-estimation method for analyzing intersections using the critical movement analysis.

Lag time—The length of time after a flight's scheduled arrival time that a passenger arrives at the airport curbside.

Landside circulation system—The airport roadway network providing for inbound and outbound traffic and the internal circulation of traffic between airport land uses.

Lane balance—A situation that exists when the number of lanes entering a roadway is equal to the number of lanes exiting the roadway.

Lane geometry—The horizontal and vertical alignment features of a roadway or roadway lane, including lane widths, grades, lengths, curvatures, tapers, and other physical features.

Lateness distribution—The distribution of passengers leaving an airport after the scheduled arrival time of their aircraft (i.e., a distribution of passenger lag times).

Lead time—As used in this Guide, the length of time in advance of a flight's scheduled departure time that a passenger arrives at the airport curbside.

Macroscopic models—Models or analytical procedures used to consider the flow of vehicle streams (or other objects) rather than the flow of individual vehicles.

***Manual of Uniform Traffic Control Devices* (MUTCD)**—The principal standard governing the application, design, and placement of traffic control devices, published by FHWA. See http://mutcd.fhwa.dot.gov.

Maximum service flow—A maximum flow rate at which vehicles can traverse a point or short segment during a specified time period at a given level of service.

Merging capacity—Maximum flow rate at a merge point.

Metropolitan planning organization (MPO)—A policy-making organization responsible for planning, analysis, and development of multimodal transportation facilities in a region or community.

Microsimulation models—Models or analytical procedures used to simulate the operation of individual vehicles (or other objects) on simulated roadway (or other) networks.

Mixed-flow traffic volumes—The numbers of vehicles in a traffic flow consisting of multiple vehicle types.

Operational characteristics—Traffic flow characteristics, including speed, density, vehicle mix, and volumes.

Passenger car equivalent (pce)—The number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions.

Passenger load factor—A measure of available aircraft seats that are occupied.

Peak hour—The peak hour is the busiest hour of the year, month, or day. It is suggested that the "design hour," rather than the peak hour, be used for planning and evaluation of airport roadways, and that the design hour be a typical busy hour on the peak day of the week during the peak month.

Peak-hour factor—The relationship between the hourly traffic volume in the peak hour and the maximum rate of flow within some portion of the hour. As used most commonly, this factor refers to the ratio of the hourly volume to the maximum 15-minute flow rate expanded to an hourly volume.

Performance capabilities—As used in this Guide, the capabilities of an individual vehicle or group of vehicles, including acceleration, maneuverability, and turning radii.

Poisson distribution—A discrete probability distribution that expresses the probability of a number of events occurring in a fixed period of time.

Remote curbside—A curbside located outside of the immediate area of the passenger terminal building, such as in a parking structure, surface lot, or multimodal facility.

Rental car ready/return—The parking or storage area(s) to which rental car customers return rented vehicles or pick up rental vehicles.

Signal phasing—The part of a traffic control signal time cycle allocated to any traffic movement given the right of way.

Skycap—A porter employed by an airline or airport operator to provide baggage drop service to passengers.

Steady-state performance—The traffic flow rates occurring on a roadway or intersection when the traffic stream is not disrupted or interrupted.

Terminal area roadways—The roadways serving the terminal building and surrounding areas, including access, curbside, and circulation roadways.

Through vehicles—As used in this Guide, vehicles bypassing the curbside area or zone. Also see "Bypass vehicles."

Time path—A person's perceived time incurred while traveling along a defined path or route, including time in motion, delays caused by congestion, and waiting time.

Traffic controls—Devices directing vehicular and pedestrian traffic flows, particularly at conflict areas, including signals, signs, and pavement markings.

Transborder flight—As used in this Guide, scheduled flights between the United States and Canada whose passengers have typically been pre-cleared by border controls.

Transportation demand management (TDM)—The application of policies and strategies to reduce travel demand or redistribute this demand in space or time.

Trip generation rate—The number of vehicle or person trips generated by a household, zone, land use, or other facility generally during a daily or peak period.

Triple parking—A situation in which three or more adjacent vehicles are parallel parked or stopped along the curbside roadway.

Weaving area—The roadway segment in which two or more traffic streams traveling in the same general direction along a significant length of roadway cross one another without the aid of traffic control devices.

Weaving distance—The distance from a point on the merge gore at which the right edge of the freeway shoulder lane and the left edge of the merging lane are 2 feet apart to a point on the diverge gore at which the edges are 12 feet apart.

Weaving intensity factor—A measure of the influence of weaving activity on the average speed of both weaving and nonweaving vehicles.

Vehicle mix—The proportion of each type of vehicle (i.e., bus, car, van, truck) in a traffic stream.

Vehicle occupancy—The number of passengers (including the driver) in a vehicle.

Vehicle stall length—As used in this Guide, the length of curb space occupied by a stopped vehicle, including the distance required to maneuver into and out of the space.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation