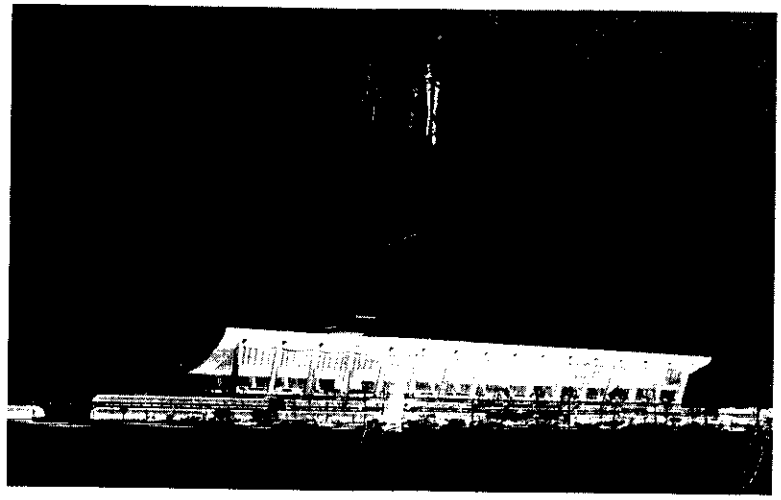
Special Report 215



MEASURING AIRPORT LANDSIDE CAPACITY

Transportation Research Board
National Research Council

Special Report 215

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Committee for the Airport Capacity Study

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Preface

Congestion at airport terminal buildings, access roads, and parking areas increasingly threatens the capability of airports to serve additional passengers and air cargo. Measuring the capacity of these airport landside facilities and services is becoming as critical to operations of major airports as capacity measurements for the airside taxiways and runways that serve aircraft. Yet the analysis procedures for assessing airport landside capacity are less developed than techniques for measuring airside capacity, and no generally accepted standards exist for gauging the level of service provided by landside facilities and their operations. The Federal Aviation Administration, in recognition of this situation, commissioned the Transportation Research Board to review existing capacity assessment techniques and recommend guidelines that can be used by airport operators, planners, and others who must measure airport landside capacity.

To undertake this study, TRB convened a committee that included airport executives, planners, researchers, consultants, the airlines, and aviation industry organizations. Meeting over a period of about one year, the committee concluded that current knowledge about the performance of various airport landside components is inadequate to support airport landside service standards at this time. Instead, the committee proposed a process for measuring airport landside capacity that takes an important first step toward developing such standards.

Part I of the report contains a general description of the airport landside, how landside capacity is defined and measured, a process for landside capacity assessment, and research needs. In Part II guidance is presented for

applying these definitions and the process to specific landside functional components likely to represent constraints on the airport's ability to satisfy demand.

The report represents the collective efforts of the committee, TRB staff, and a host of airport operating agencies who provided valuable data and assistance. The study was performed under the overall direction of Dr. Damian J. Kulash and Robert E. Skinner, the former and current Directors for Special Projects. Dr. Andrew C. Lemer, the project director, conducted the review of existing capacity measurement techniques and drafted much of the report under the direction of the committee.

Special appreciation is expressed to Nancy A. Ackerman, TRB Publications Manager, for publication of the final report, and to Marguerite Schneider and Frances E. Holland for typing drafts and the final manuscript.

Contents

Executive Summary

The Federal Aviation Administration (FAA) expects the annual number of passengers using the nation's airports to grow more than 70 percent above 1986 levels in the next 10 years. To accommodate this growth, many airports must add new facilities or make better use of existing facilities or do both. Airport operators and local officials must make decisions about airport use and expansion against a backdrop of local economic, environmental, and social consequences. Airlines and the FAA, on the other hand, view the operation and expansion of individual airports from the standpoint of the role they play in providing an efficient national air transport system. Regardless of their different perspectives, each needs reliable estimates of airport capacity to make decisions about airport expansion and operations.

An airport may be divided into two parts: the airside—runways, taxiways, and air traffic control systems used by aircraft and pilots—and the landside—aircraft parking positions and gates, terminal buildings, baggage services, access roadways, and automobile parking structures used by passengers. Capacity problems may occur in either airside or landside facilities and services. Extensive research and practical experience have produced widely accepted procedures for assessing an airport's airside capacity. The FAA sanctions these procedures, and they are applied throughout the United States and in many other countries. However, similar guidelines are not available for assessing landside capacity. As a first step toward developing such guidelines, a special 18-member Transportation Research Board committee reviewed current practice and recommended a process for assessing the capacity of airport landside facilities and services. The committee concluded that generally accepted definitions and procedures for capacity assessment are needed.

Data collection and research will be required to produce more definitive guidelines that will yield consistent capacity measures for the many diverse conditions found in airports throughout the United States.

MEASURING CAPACITY

Landside capacity refers to the capability of the airport's landside facilities and services to accommodate passengers, visitors, air cargo, ground access vehicles, and aircraft. Of these, the capability to serve air passengers is the greatest concern. Other aspects of landside operations such as cargo shipments and aircraft maintenance are included in this report only to the extent that they directly influence passenger service. Passengers impose a variety of demands on parking facilities, ticketing, baggage claim, and other landside components. These demands are influenced by when and how passengers arrive at the airport, the number of bags they carry, their age and trip purposes, the number of people accompanying or meeting them, and myriad other characteristics.

Estimates of passenger capacity are meaningful only when they are referenced to the service level provided to passengers. Service level includes factors such as waiting time, processing time, walking distance, crowding, and availability of passenger amenities for comfort and convenience, many of which may be difficult to measure. Passenger demands and facilities operations interact to determine service level and capacity, making the measurement of capacity an iterative process.

When passenger demands are large, landside components may operate at maximum throughput rates, which reflect the greatest number of passengers that can be processed in a given time by a component or group of components. Typically, however, maximum throughput can be sustained only during periods when demand is high and then only briefly, because significant passenger delays and crowding usually develop and disrupt operations. The recommended measure of landside capacity is service volume, which is the number of passengers that can be accommodated by a functional component or group of components in a particular time period relative to a particular demand at a given service level. Service volume is typically measured for periods of 15 min, 1 hr, 2 hr, or sometimes a full day. Although there are a number of landside service-level indicators that may be important at a particular airport, total passenger processing time (including service time and delay) and crowding are the most important.

Many airports could accommodate a greater number of passengers if new demands occurred during quiet periods of the day or if passenger processing times and crowding were allowed to increase. The level of acceptable delay and crowding that may limit capacity will in general vary from airport to airport. Airport operators may set explicit service-level targets that can be used as guidelines to assess a particular airport's landside capacity and guide decision making about management and development of landside facilities and services. The FAA, airlines, and airport operators need to establish common service-level targets that can be used when comparing conditions among airports and discussing issues of significance to national airport system operations.

CAPACITY ASSESSMENT PROCESS

Landside capacity assessment must respond to a variety of questions and issues about airport operations and planning, ranging from how existing gates and ticketing facilities should be used to when a new terminal building may be required. The specific problems a capacity assessment must address determine which component facilities and services must be considered. An airport's landside capacity can be measured only in terms of its individual functional components.

The recommended assessment process is based on this premise that landside capacity cannot be assessed without estimating service levels and service volumes for individual components (Figure ES-1). Specific passenger demand must be known or assumed, as well as relevant airline and airport operating policies and procedures. Interaction and feedback among particular steps in the process are critical. Service levels and capacity measures can be assessed only with reference to one another. Performance of any single landside component may depend on performance of other components with which that component interacts. Service-level targets set for current conditions may have long-term implications for the airport's future development. Only by successively considering how individual components perform and how they interact with one another and with demand can their potential service levels and service volumes be determined and a meaningful estimate of landside capacity be derived.

All landside components are important, but not all are likely to cause passenger delay and crowding or become significant to determining an airport's landside capacity. Newsstands, public telephones, restaurants, and rest rooms are essential amenities, yet they are seldom a basis for estimating landside capacity. The committee identified critical landside components or component groups and assembled guidelines for assessing the capacity of each:

- Aircraft parking position and gate
- Passenger waiting area
- Passenger security screening
- Terminal circulation (corridors, stairs, etc.)
- Ticket counter and baggage check
- Terminal curb
- Parking area
- Ground access

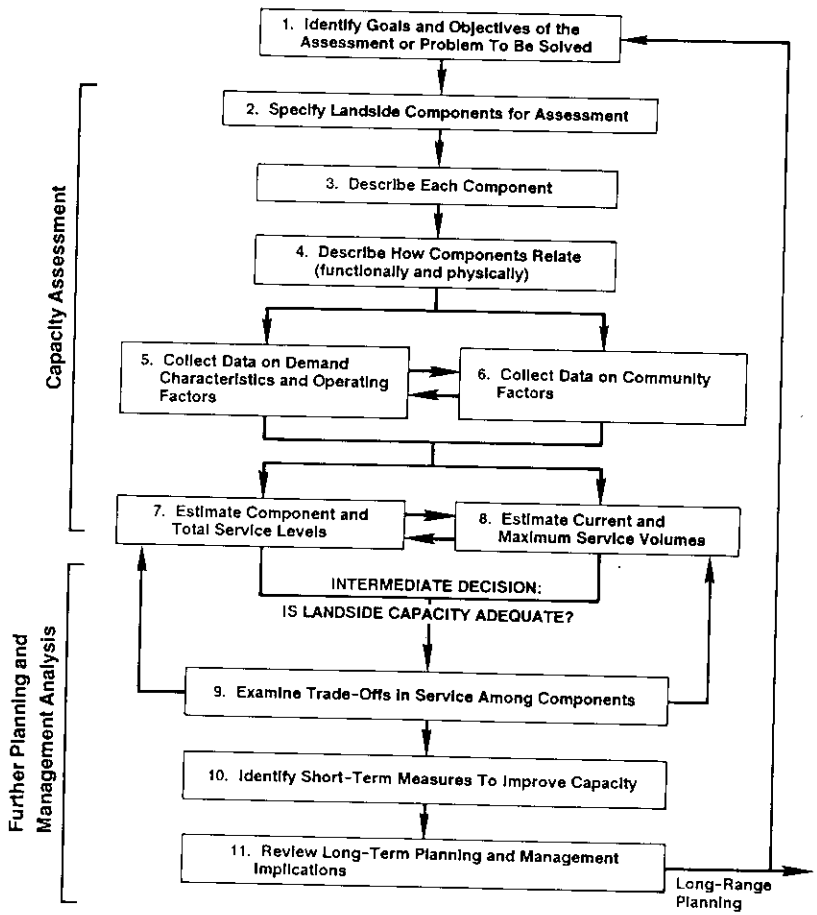

FIGURE ES-1 Landside capacity assessment, management, and planning process.

- Baggage claim
- Customs and immigration
- Connecting passenger transfer

The committee also described how capacity analyses for individual components may be used to estimate capacity of the landside system as a whole, particularly within a context of strategic management and longer-range planning.

COMMUNITY FACTORS

Airport planning and operational studies must take into account how the surrounding community may influence capacity. In addition to air passengers, this community includes cargo shippers and other airport users, neighboring residences and businesses, and local and state government. Airport operators must work with this community, the airlines, and the FAA to operate and develop the airport to meet the demand for aviation services. If the community perceives that the benefits of these services are outweighed by such problems as noise and highway traffic associated with the airport, they may seek to restrict the airport's operations.

Restrictions may take the form of policies that limit expansion of airport landside facilities or they may curtail permissible aircraft operations. The community's influence may also include promoting development of new landside facilities to attract users and investment. In either case, the demand on landside facilities or the ability to provide new facilities will be affected.

NEED FOR FURTHER RESEARCH

Airport operators and others cannot conduct consistent landside capacity assessments at different airports without uniform service-level targets that distinguish between excellent, adequate, and poor service. Although the study identifies which landside services should be covered and how service-level targets can be related to different types of air travel, the committee concluded that available data are inadequate to support proposal of firm service-level targets. Research to assemble a data base on landside operating and service conditions is needed: specific data are needed to describe typical crowding, delay, and other relevant service-level indicators for all types of airports in the United States. The FAA should work with airport operators and airlines to develop a coordinated research program to collect such data, which industry could use to establish service-level targets.

Part I
Definitions and Process

Although many people have some intuitive understanding of what conditions occur when demand on an airport's landside facilities and services is close to that airport's landside capacity, there appears to be little general agreement among airport and aviation professionals on how landside capacity should be defined and assessed. In Part I of this report major landside capacity issues being faced by operators of many airports in the United States are reviewed, the terms needed to establish a common understanding of landside capacity are defined, a process for assessing the landside capacity of a particular airport is described, and research is recommended that is needed to move the airport and aviation industry toward generally accepted standards for measuring and judging whether the landside capacity of an airport is adequate to meet the demand on its landside systems.

1
Background

Airports serve a broad and complex range of needs related to the movement of people and goods. Passengers and cargo shippers gain access to national and international air transportation through airports. Airlines and other operators of aircraft use airport facilities to serve passengers and shippers and to operate, maintain, and store their aircraft. Concessions offer a variety of products and services to passengers, visitors, and airport and airline employees. The community served by an airport may depend on the airport for transportation, jobs, business opportunities, and recreation, but may be exposed to aircraft noise and to the growing need for land to expand airport facilities.

Although it is difficult to draw a precise line separating the two areas, airport and aviation professionals speak of airports in terms of "airside" and "landside" components. The Federal Aviation Administration (FAA) defines the airside as "the airfield and its components (i.e., runways, taxiways, and apron-gate areas)" *(1)*. Aircraft operate within this airside system and the accompanying airspace under the federal government's air traffic control procedures and regulations. In this report, apron-gate areas are included in the landside and described as aircraft parking positions and gates.[1]

The airport landside includes terminal buildings, access roads, and parking areas and the services provided for users of these facilities. Passengers, employees, cargo, and aircraft maintenance activities use an airport's landside facilities and services. However, this report addresses only those aspects of an airport's landside system that relate directly to air passenger capacity and available methods for assessing that air passenger capacity. The remainder of

this chapter is devoted to discussion of the need for landside capacity assessment procedures and key issues currently affecting airport landside capacity.

MOTIVATION FOR A LANDSIDE CAPACITY STUDY

The airport landside is controlled to a great extent by the local community that owns and is served by the airport. This community includes airport users, airport neighbors, and local and state governments. In addition to this airport-related community, the airport operators must also work cooperatively with airlines and the FAA. Each of these groups may deal directly with any of the others on matters affecting the airport (see Figure 1-1). Airlines operate at an airport generally under terms of leases on terminal building space and gates. The FAA administers programs to support airport planning and development of airport facilities and to ensure an effective and safe national air transportation system. The interaction among these groups is the context within which airport operating and development decisions are made—decisions that influence and are influenced by landside capacity.

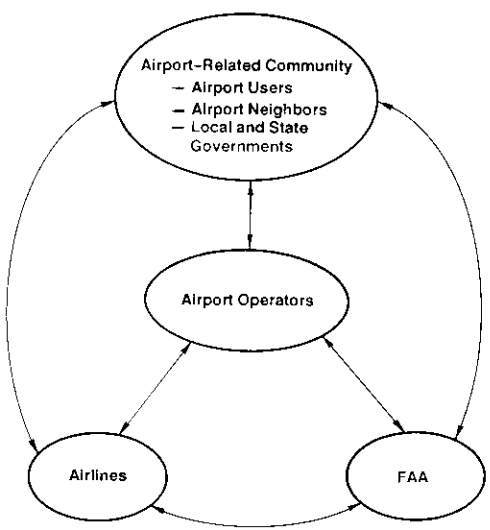

FIGURE 1-1 Groups participating in airport landside management.

Extensive research in the United States and abroad has produced methods for airside capacity assessment and facilities planning and design. The FAA, responsible for airside safety and for development of the national air transportation system, has published recommended procedures for airside capacity assessment *(2)*.

In comparison with the airside analysis, procedures for landside capacity assessment, planning, and design are less clearly defined *(3)*, and although several professional organizations and the FAA have published guidelines, there are few generally accepted procedures and practices. A representative of the U.S. Department of Transportation, participating in a 1975 conference on airport landside capacity sponsored by the FAA and the Transportation Systems Center, wrote *(4)*:

> The problem of improving landside capacity of airports is an elusive one. At present, we do not even have a standard against which to measure existing levels of airport service or by which to outline desirable levels of service.

In the decade since that conference and in a climate of substantial change in the aviation industry, airport professionals have been able to shed little light on the problem.

The FAA expects the number of passengers using the nation's airports in 1998 to increase more than 70 percent over 1986 levels, from 409.6 million annual enplanements in 1986 to 696.8 million by 1998. During this same period, annual air passenger carrier operations are forecast to grow 32.5 percent, from 12.3 million to 16.3 million. Air taxi and commuter operations are projected to grow from 6.9 million to 10.9 million, or nearly 58 percent over the period *(5)*.

Such growth will present challenges to the nation's air transportation system. The FAA forecasts that larger and perhaps more fully loaded aircraft will be operating at the nation's airports. These aircraft and their passengers will place increasingly greater demands on airport landside facilities. Although the technical issues of landside capacity may be elusive, passengers know by the long delays and crowded conditions when landside facilities and services are being strained. Although the majority of the nation's airports generally have few landside problems, the need for procedures to assess and manage landside capacity will continue to grow.

Some efforts have been made by international organizations to provide guidance on landside capacity analysis. The International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) have published manuals *(6-8)*. However, practice in the United States depends on a small number of typically older, key technical publications *(9-11)* and the accumulated experience of individual practitioners.

Recognizing this situation and the importance of the landside in efficient operation of the nation's air transportation system, the FAA requested the Transportation Research Board (TRB) to conduct a study in which technical guidance to support assessments of airport landside capacity would be developed.

CURRENT ISSUES AFFECTING LANDSIDE CAPACITY

Many aspects of landside capacity depend on the unique character of an individual airport and the community values within which the airport operates. Broad organizational, legal, and political issues influence the judgment of the practical limits of landside capacity. Although the details of facility sizes and operating practices that influence landside capacity may differ from one airport to another, the broad issues are often similar. Four major issues in particular influence landside capacity at many airports—airline leases on airport facilities, shifting patterns of airline operation, changing procedures for passenger processing, and a range of community effects on airport operations. The landside capacity assessment process must be able to respond to such institutional and management issues as well as to the details of facilities and services of airport and airline operations.

Airline Leases on Airport Terminal Facilities

Airlines typically lease airport terminal facilities from the airport operators. In the majority of cases, these leases give each airline exclusive rights to use particular gates and terminal areas. The passengers of one airline may sometimes experience crowding and delay associated with inadequate capacity whereas at the same time another airline's facilities at the same airport stand relatively empty. Each airline is responsible for the complex task of using its leased facilities efficiently, taking into consideration its operating costs, customer relations, and competitive position in scheduling this use.

Until the early 1980s, airline leases historically had long terms. Such long-term lease agreements have traditionally given greater security to the airport operators and supported the sale of reasonably priced long-term revenue bonds to fund capital improvement programs.[2]

Three-fourths of the major airports in a 1975 survey had lease terms exceeding 10 years. Of those airports at which airlines were committed to pay the difference between actual airport operating costs and revenues in a given

year, 89 percent had lease terms longer than 10 years.[3] At some airports long-term ground leases permit the airlines to construct their own terminals, to which they retain ownership rights. Under such long-term and legally binding arrangements, airlines can control much of an airport's facilities, and the airport operator may have a limited ability to respond to changes in air passenger demand and airline route structures, competitive practices, and commercial health.

Airline deregulation appears to be encouraging some airport operators to adopt lease terms that afford greater flexibility in facilities management. Some airlines as well appear to prefer the reduced commitment associated with shorter lease terms, although other airlines recognize the influence of lease terms on an airport's ability to raise capital and continue to enter into long-term leases. Airports with strong local markets—rather than a great deal of transfer traffic—are typically in a stronger financial position and may therefore operate more independently of the airlines.

At some U.S. airports and most foreign airports, airlines share gate and other terminal facilities. Under joint gate use, gates are assigned to aircraft as they arrive. Preference is given so that airlines can expect to have all their gates grouped in a particular area, but no airline holds exclusive rights to any gate. Joint gate use may allow the airport to serve a greater number of aircraft and passengers at any given time with a smaller number of gates. At Hawaii's major airports, for example, where gates are shared in this manner, numbers of annual aircraft operations per gate are higher than might otherwise be expected, and are comparable with those at the largest and busiest mainland airports. Airports at which a large airline hub-and-spoke operation is based may have very high gate utilization as well under an exclusive gate use strategy, as explained later.

Changes in Airline Operating Practices and Market Behavior

Many airlines have tried to attract customers and improve efficiency by assigning seats and issuing boarding passes to passengers before their arrival at the airport. Machines are now available in many airports (and even downtown or at local shopping centers) that enable a passenger to purchase a ticket and receive a boarding pass by using a credit card. This practice reduces both the number of people who must stop at the ticket counter before going to the gate and the need for ticket counter space in the terminal. The effective capacity of the terminal gets a small boost.

The airlines' continuing efforts in an open competitive environment to fly their aircraft fully loaded have generated such practices as discounted standby

and bulk sales of available seats. New passenger traffic may be attracted by discounted fares. Even when total passenger traffic does not grow, increasing crowds of passengers waiting in areas adjacent to gates for changes in their flight, seating, or class of service may be the sign of a terminal area experiencing a landside capacity problem.

Particularly significant for landside management are the effects of airline hub-and-spoke operations. For such an operation an airline selects an airport as a central point for many of its routes and uses that airport (the "hub") as a transfer point to allow passengers a wide combination of origins and destinations by using a relatively small number of direct flights (the "spokes"). Gate areas may be very crowded for one hour when many flights converge and then may be empty the next hour. Requirements for terminal facilities serving such an operation are quite different from those for an operation serving primarily origination and destination traffic. Because there are several such peaks of activity during the day, gate utilization is much higher than is usually the case at an airport without such an airline hub-and-spoke operation.

Airlines also try to serve demand most profitably by using aircraft that match seating availability closely to route demand. High-density routes fed by hub-and-spoke operations call for larger-capacity aircraft.

When the Boeing 747 and other widebody aircraft were first introduced, airport gate lounges, concourses, and baggage claim areas had to contend with a larger surge of passengers arriving at one time than had been previously experienced. More gate lounge and baggage claim space was required to handle one widebody aircraft arrival than was needed for several small aircraft. This is still a problem at some airports when widebody service is introduced. Anticipated introduction of the 500-seat Boeing 747-500 is causing concern among airport operators, and even larger aircraft may be developed *(13)*.

Changes in Passenger Processing

Curbside baggage check operations coupled with advance ticketing and seat assignment reduce the number of passengers who must stop at the ticket counter. But some airport operators believe that concerns for airport security in the 1980s could lead to broader restrictions on curbside baggage checking. Such checking has already been eliminated at many airports in those areas serving international traffic. The effective capacity of some terminal facilities might then be reduced as more space is required for passenger and baggage processing. The situation could be further aggravated if proposals to curtail sharply the practice of carrying luggage onto the aircraft are adopted.

At the destination, reduced interline transfers (a result of the increased airline hub-and-spoke operations mentioned earlier) may improve the speed of baggage arrival and subsequent passenger departure from the airport by reducing the number of passengers and baggage being transferred from one airline to another. Increased use of computers for customs and immigration inspection of arriving international passengers may have a similar effect.

Community Effects on Operations

Although some communities actively seek to expand their airport business activities and to attract new service, a few jurisdictions have imposed restrictions on aircraft operations to reduce the levels of airport noise to which neighbors of the airport are exposed or to limit demands on already inadequate facilities. These restrictions may limit flights scheduled for nighttime operations or may limit the number of passengers an airport can serve annually. Sometimes restrictions may be placed on the types of aircraft operating at the airport. Such restrictions may have a direct effect on how gates, roadways, and other airport facilities can be used, and thereby influence capacity.

SCOPE OF THE REPORT

This report is written to support the assessment of landside capacity at a particular airport. Because of the great variety of conditions at different airports, a single set of simple numerical parameters and procedures applicable to all airports is not feasible. Instead, assessment should be tailored to the specific problem at hand and conducted at a level of complexity appropriate to the type of decision being made. Airport and aviation professionals may use landside capacity assessment to decide whether a new terminal building is needed or to estimate the number of x-ray devices to be staffed and in operation during a midday period or how much space to cordon off for baggage claim for a special charter flight. Guidelines on how to conduct landside capacity assessments are given in Part I of this report by providing basic definitions (Chapter 2) and an assessment process (Chapter 3) and by describing the influence of community factors on available landside capacity (Chapter 4). In Part II the capacity assessment process is applied to key landside components.

NOTES

1. See the glossary for definitions of terms.
2. A study by the Office of Technology Assessment (OTA) *(12)* found that in 1975–1976 approximately 30 to 50 percent of the revenues of commercial airports came from concessions and rentals of terminal facilities. Airside-based charges such as aircraft landing fees and aviation fuel sales compose another major source of airport revenues.

3. This basis for leasing is termed the "residual-cost" approach to airport financial management and was used at an estimated 58 percent of larger airports in 1983.

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2
Basic Definitions

Despite general agreement among airport and aviation professionals on major principles, precise meanings of many terms related to landside capacity may vary. To establish a basis for developing a landside capacity assessment process, definitions for the key terms that are used throughout this report are presented in this chapter. The glossary at the end of the report includes these terms and others that have particular importance in the understanding of landside capacity.

The main focus in this report is on air passenger capacity at commercial service airports. Nevertheless, any discussions of landside and landside capacity must also consider air cargo and general aviation users as well as airport employees and visitors who use the airport's landside facilities and services.

AIRPORT LANDSIDE, AIRSIDE, AND COMMUNITY

For this report, the airport landside is defined to include all facilities and services associated with an air passenger's ground-based journey from trip origin to the aircraft and from the aircraft to the destination of the trip. The landside includes ground access, terminal buildings, roadways and parking, ticketing, baggage handling, and aircraft parking positions and gates (Figure 2-1). Landside capacity depends on the type, size, configuration, and condition of such facilities and on how they are staffed, operated, and regulated.

In broad terms, the landside includes the entire ground transportation system linking an airport to the region it serves. Except for special airport access services such as those to remote terminals, mass transit stations, and

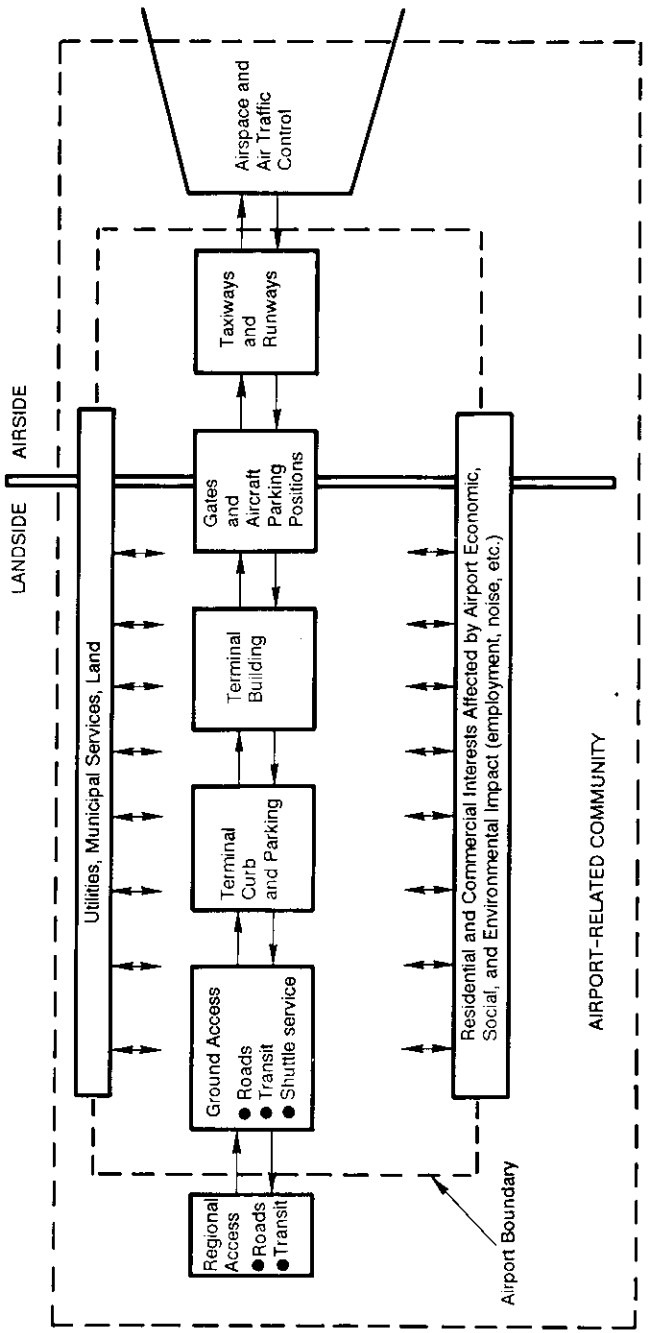


FIGURE 2-1 Functional view of an airport.

central business districts or limousine services, the dependence of an airport on this system and on other municipal services decreases with their distance from the airport. The airport operator's ability to control these facilities and services decreases with increasing distance as well. As a practical matter, the boundary of the landside may often be drawn at the major links between the region's ground transport and municipal service systems and the airport, along the airport's property boundary, and at the door of the aircraft.

Although many components of the airport landside influence the air passenger's comfort, safety, and convenience, landside capacity is determined primarily by those components that are or may become real constraints to passenger movement to and from the aircraft.

The airside includes the facilities and services used by aircraft to transport passengers and cargo. In this report, taxiways and runways, airspace, and air traffic control systems are included in the airside. Passengers are in effect part of the airside while they are on board an aircraft and making no demands on landside facilities (although the aircraft itself is still parked and therefore on the landside).

The airport-related community includes airport users, neighbors, and local and state government. This community provides land, labor, financial support, infrastructure, and municipal services to the airport and receives a variety of benefits (e.g., air service, employment) and some adverse effects (e.g., noise, traffic congestion). The community's perceptions of and response to these benefits and adverse effects can influence an airport's capacity (see Chapter 4).

FUNCTIONAL COMPONENTS AND CAPACITY DETERMINANTS

An airport's landside is a complex collection of individual functional components such as the following (see glossary for definition of terms). Those components in italics are considered potentially critical to landside capacity and are discussed in detail in Part II of this report.

Environs
- *Ground access*
  - Remote terminals
  - Transit links
  - Highway links
    - Remote parking and shuttle
    - Access roads/interchanges

Air freight and air-related industrial land and buildings

Airport grounds
- Approach roads
- Remote processing facilities and services
- *Parking areas*
  - Taxis
  - Private vehicles
  - Rental cars
- Circulation/distribution roads
- Cargo docking area

Terminal building
- General configuration
  - Pier
  - Satellite
  - Linear
  - Transporter
- *Terminal curb*
  - Departures
  - Arrivals
- Terminal transition
  - Entryways and foyers
  - Lobby area
- Airline facilities
  - Office
  - *Ticket counter*
  - *Baggage check*
  - *Baggage claim*
- *Circulation*
  - Corridors, stairs, escalators
  - *Security screening*
- Passenger amenities
  - Food/beverage, news/tobacco
  - Drugs, gifts, clothing, florists
  - Barber and shoeshine
  - Car rental and flight insurance
  - Public lockers and telephones
  - Post office

  - Amusement arcades, vending machines
  - Restrooms and nurseries
  - Showers and health club
  - Chapels
  - VIP waiting areas
- Departure lounges *(passenger waiting areas)*
- International facilities/Federal Inspection Services (FIS)
  - *Immigration and Naturalization*
  - *Customs*
  - Plant and Animal Health (Agriculture)
  - Public Health
- Airline operations
  - Flight operations/crew ready rooms
  - Valuable/outsized baggage storage
  - Air freight and mail
  - Administrative offices
- Airport operations and services
  - Offices
  - Police
  - Medical and first aid
  - Fire fighting
  - Building maintenance
- Building mechanical systems
- Communications facilities
- Electrical equipment
- Government offices
  - Air traffic control
  - Weather
  - FIS and public health
- Conference and press facilities

Apron-gate system
- *Aircraft parking positions and gates*
- Passenger enplanement/deplanement
  - Waiting areas
  - Bridge
  - Stairs
  - Mobile conveyance

Apron utilities
- Fuel
- Electric power
- Aircraft electrical grounding
- Apron lighting and marking

Cabin services, aircraft maintenance
Aircraft parking and circulation

Support systems
- Power, water, and sewer
- Fuel storage

Development restricted areas
- Clear zones
- Noise exposure zones

Individual functional components of an airport interact to provide service to air passengers. Some of these components can become bottlenecks or "choke points" in the processing of passengers, causing delays and crowding. Often the symptoms of inadequate capacity may be apparent primarily to those passengers actually using the affected component. Whether or not such choke points occur depends on the design and operation of the functional components and on the demands placed on these components. Any of these functional components may become a constraint on landside capacity.

The term "demand characteristics" refers to the number of air passengers and those aspects of their behavior that materially affect the ability of a functional component or group of components to accommodate passengers. Demand characteristics include distribution of passenger arrivals over time, modes of travel to and from the airport, number of bags carried and checked, passenger's age, trip purpose, number of people accompanying the passenger, and whether the passenger has a ticket and boarding pass. Airlines often try to tailor their services to their passengers' demand characteristics.

Landside capacity refers to the capability of an airport's landside or its functional components to accommodate passengers, airport visitors, air cargo, ground access vehicles, and aircraft. This report focuses on air passenger capacity, the number of air passengers who can be served by airport landside components in a given period of time. A variety of passenger capacity indicators exist, reflecting either flow rates (passengers per unit of time) or crowding (the number of passengers within a specific area during a given time period). Because those waiting at the airport are only temporary occupants and waiting areas may fill and empty several times during a typical day, even crowding indicators are a reflection of passenger flow through the landside.

Flow-rate capacity indicators vary between the *maximum throughput*[1] and a lower *service volume* that results from *service-level* consideration, demand characteristics, and other limitations. Crowding capacity indicators at maximum throughput may signal crush conditions or reflect a lower service volume that maintains service levels consistent with passenger safety, health, comfort, and convenience. For both flow rates and crowding, service volume is the principal capacity indicator used throughout this report.

Capacity can be evaluated for an individual functional component of the airport landside, such as a ticket counter or aircraft gate, or for groups of components. Those components that are most likely to become constraints on landside capacity (Figure 2-2) are described in detail in Part II. For purposes

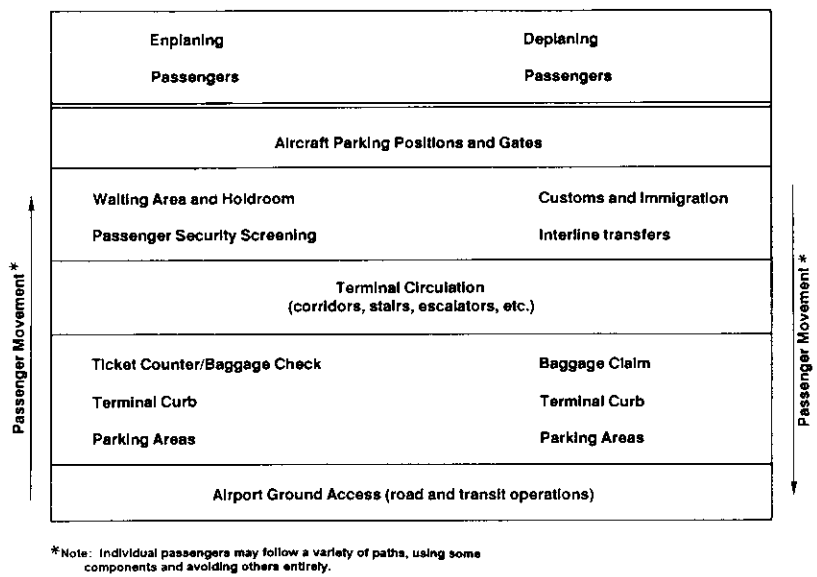


FIGURE 2-2 Landside components most likely to determine capacity.

of this report, components such as concession areas, rest rooms, and telephones, although important passenger amenities, are not a basis for defining airport landside capacity.

Maximum Throughput

Maximum throughput is the maximum rate at which passengers can be processed by a functional component or group of functional components. In

practice this rate is actually observed only when demand equals or exceeds the component's processing capability, and is typically sustained for only brief periods of time, because excess passenger demand usually produces significant passenger delays and crowding that disrupt operations.

As an example of what happens when a component operates at maximum throughput, consider the case of a single ticket counter staffed by a single agent. Passengers arrive at the ticket counter to check baggage, purchase a ticket, receive boarding passes, or simply ask a question. If there is a queue at the counter, a new arrival must await his or her turn before moving onward through the airport toward his departing flight. If everyone using the ticket counter requires exactly the same service and if the agent at the counter maintains consistent performance, then each person might be served in exactly the same amount of time—say 5 min per person.

The number of passengers who could be served by this agent would then be 12 per hour. This rate is the ticket counter's maximum throughput. If this rate continued throughout a 24-hr day, the ticket counter could in theory serve up to 288 passengers per day (Figure 2-3).

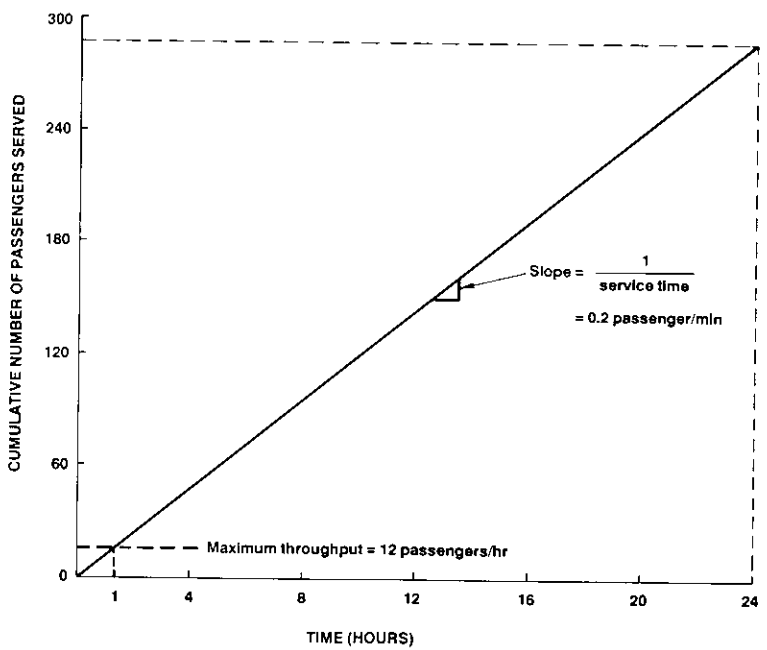


FIGURE 2-3 Maximum throughput for an example ticket counter.

Service Level

The quality and conditions of service of a functional component or group of functional components as experienced by passengers constitute the service level. Factors such as waiting time, processing time, walking time, crowding, and availability of passenger amenities for comfort and convenience are measures of the service level of components. Many of these factors are interrelated, and there may be others of importance at a particular airport. There are a variety of ways in which some of these factors may be measured, whereas other factors may be difficult to quantify. An analyst may choose any number of specific measures for capacity assessment.

As long as passengers arrive at the example ticket counter, manned by a single agent, at a rate no greater than the rate at which they can be served (in this case, one passenger arrival every 5 min), there will be no queue and no waiting for service. If a passenger arrives at the counter before the previous arrival has been served and has departed, this new passenger will have to wait. As more passengers arrive, a queue may begin to grow. When the rate of arrivals drops, the agent at the counter may begin to catch up, and the length of the queue will begin to decline (Figure 2-4).[2] In this case, after 2 hr, 24 passengers had arrived, 5 were in queue, and 19 had been served. The length of time that each person will have to wait for service is directly related to the length of the queue when he arrives. Because the arrival of passengers at the counter is random, service level fluctuates frequently. As a practical matter, service volume is measured as an average or expected maximum over a period of 15 min, 1 hr, or sometimes several hours.

In theory if the rate of arrivals stays higher than the service rate, the queue can keep growing and service level can keep declining. However, in a real situation, passengers would begin to miss their flights and the terminal lobby would be too full to hold more people. Even before conditions become that severe, passengers would complain.

Typically an airline or airport operator will decide that there is some level of delay or queue length that is the maximum acceptable. As an example, the airline using the single ticket counter might decide that maximum passenger processing time (including time waiting in line) should be 15 min. Delays exceeding that will trigger assignment of a second ticket agent to work at the counter (Figure 2-5).

This maximum expected wait time of 15 min is an example of a service-level target, which is the minimum tolerable service level set for a functional component or group of components in a specific *analysis period*. The analysis period used may be a peak hour, a particular holiday season, or some other period of time during which capacity problems may develop. Airport operators may set service-level targets to guide decision making affecting the development, operation, or management of the airport landside.

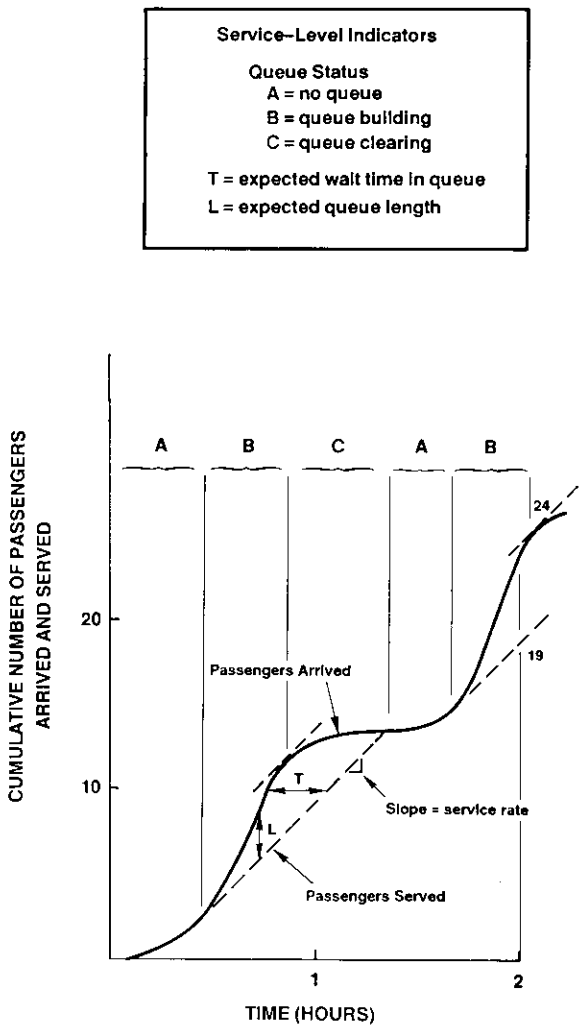


FIGURE 2-4 Service-level changes at the example ticket counter.

Each airport, and each component of an airport's landside, has unique operating characteristics and demands placed on it. It is thus extremely difficult to suggest service-level targets that can be used at all airports under all conditions. However, experience can suggest how to define service levels and targets, and with further research and development it may be possible to

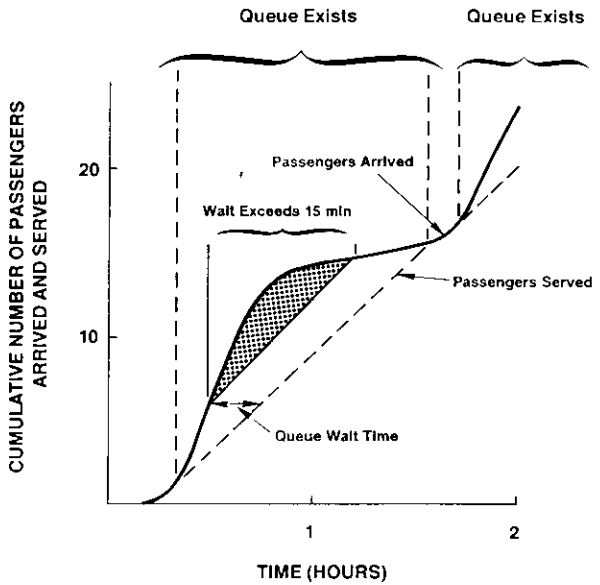


FIGURE 2-5 Definition of unacceptably low service level for the example ticket counter (dotted area indicates time during which service level not met unless second ticket agent assigned to work).

adopt generally useful guidelines for such definitions. Examples of how such service-level targets have been defined in Canada and Europe are included in Part II of this report, and research to provide a basis for adopting common guidelines in the United States is recommended in Chapter 5.

In a study made for this report, an attempt was made to develop service-level targets for U.S. airports. However, the study committee found that available data on service levels are inadequate for development of defensible and valid targets. Nevertheless, the framework devised by the committee for developing targets is a useful starting point; it is presented in Appendix A.

Service-level targets have financial and political implications. Individual communities may wish to maintain particular service levels at their airport to attract new business or simply as a matter of community goals. Maintaining targets may require development of new facilities or new operating and management strategies.

Service Volume

Service volume—the principal measure of capacity—is the number of passengers that can be accommodated by a functional component or group of components at a given service level given the demand placed on that component. For components where passenger processing takes place, such as the ticket counter or security screening, service volume may be measured as a rate (passengers per unit of time). For components where passengers wait or stand in queues, service volume may be measured as the number of passengers accommodated at any given time. For components that involve both passenger waiting and processing, both measures may be appropriate.

The demand on the example ticket counter—the number of passengers who arrive in a given period of time—fluctuates from time to time, as was shown in Figure 2-4. Arrival rates tend to increase as the time of a flight departure approaches. If there is only one flight, the rate of arrivals will decline close to the scheduled departure time (and should of course drop to zero once the flight has departed).

The service volume that can be accommodated at the example ticket counter manned by a single agent is only 19 passengers over the 2-hr period (Figures 2-4 and 2-5), even if 24 passengers arrive and a waiting time in excess of 15 min is acceptable. If a service-level target is set—for example, that the expected wait at the ticket counter should never exceed 15 min—then even fewer passengers can be served. If the average service rate is 5 min per person, setting this target means that if there are more than three passengers at the counter, the service-level target is not met (Figures 2-5 and 2-6). To maintain this target service level, airlines might assign additional agents to counter positions when passenger arrivals are expected to be greatest. Because demand characteristics at any component are seldom exactly matched to the component's service rate, over longer periods of time achievable service volume is generally less than maximum throughput (Figure 2-7).[3] Airlines adjust to the patterns of demand by assigning additional personnel and by allowing service levels to decline during busy periods. The fixed physical facilities of the airport are often designed to allow for some variation in demand and growth in traffic. Capacity problems can arise from the way in which facilities are operated as well as from a shortage of these facilities.

CAPACITY ANALYSIS PERIOD

Capacity becomes a problem during those periods when demand is high. Although these periods may be limited at some airports, at others demand is high during much of the day. Capacity assessment must estimate service

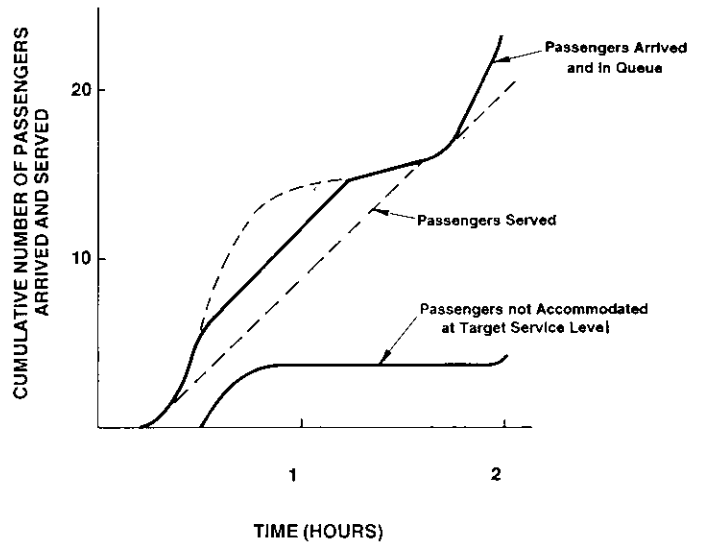
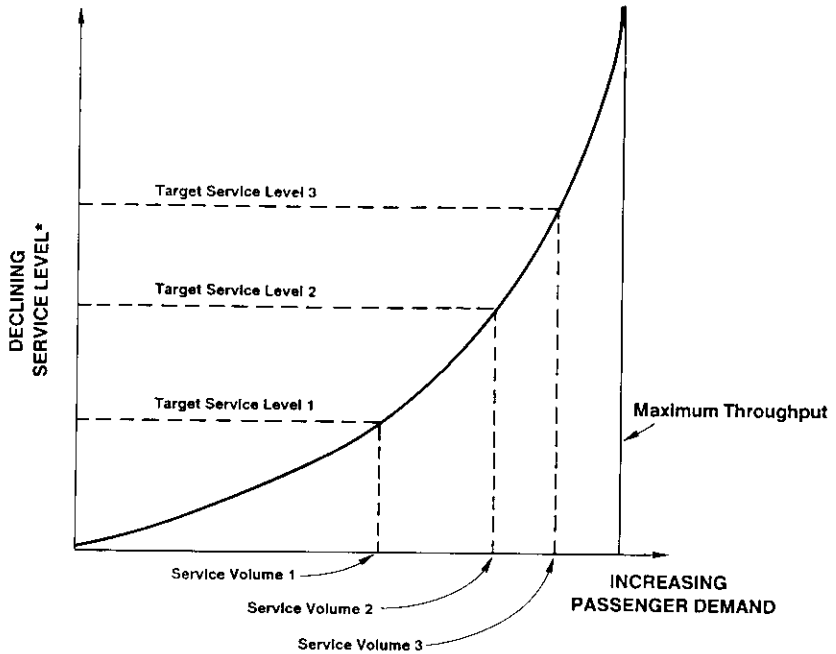


FIGURE 2-6 Influence of service-level targets on service volume at the example ticket counter.

volume and service level for a landside functional component or group of components during a specific analysis period. The appropriate analysis period depends on the type of component or components and the characteristics of the demand placed on that component. For some components the appropriate analysis period may be an hour or less, for others a series of hours, and for some perhaps as long as a day. Usually the analysis period is selected to coincide with a period of concentrated demand, for example, a peak hour or busy hour. Service volumes may be set for longer periods of time, such as a month or a full year, but the study committee believes that capacity cannot be meaningfully assessed over these longer periods.

The busiest times at many U.S. airports are the few days immediately before Thanksgiving and Christmas. Airports serving southern beach resort areas will often have more traffic in the winter months. Summer vacations make August a busy month at many airports. Regardless of the time of year and the flight schedule, passenger demand varies from month to month, from day to day in a week, and during a day in a pattern that is relatively predictable from historic records. The analysis period should reflect realistic recurring conditions and not the worst possible case at an airport. It is uneconomical to try to maintain the highest service levels under all demand conditions.



*Determined by service-level indicators (wait time, service time, crowding)

FIGURE 2-7 Schematic relationship among sevice level, service volume, and maximum throughput.

In some European countries, the Standard Busy Rate (SBR) is defined as the anticipated level of demand during a busy hour *(1)*. For example, at Amsterdam's Schipol Airport, demand levels during the 20th busiest hour are used, and in France, Aeroports de Paris uses the 40th busiest hour. (There are 8,760 hr in a 365-day year.) The British Airports Authority defines the Busy Hour Rate demand as the level such that 5 percent of annual passenger volume occurs at higher hourly rates (see Figure 2-8). The International Air Transport Association (IATA) recommends that high-traffic holiday periods be excluded in selecting busy periods *(2)*.

Transport Canada now conducts capacity evaluations by using the 90th-percentile hour, defined similarly to the British Busy Hour Rate, but considers the variations in demand within this peak period *(3)*. Passenger loads that are maintained or exceeded for a 15-min period during this peak hour are the basis for assessing service level. FAA guidance material uses the peak hour of an average day of the peak month as a basis for planning and design *(4)*, which is common practice in the United States. If, for example, August is the month

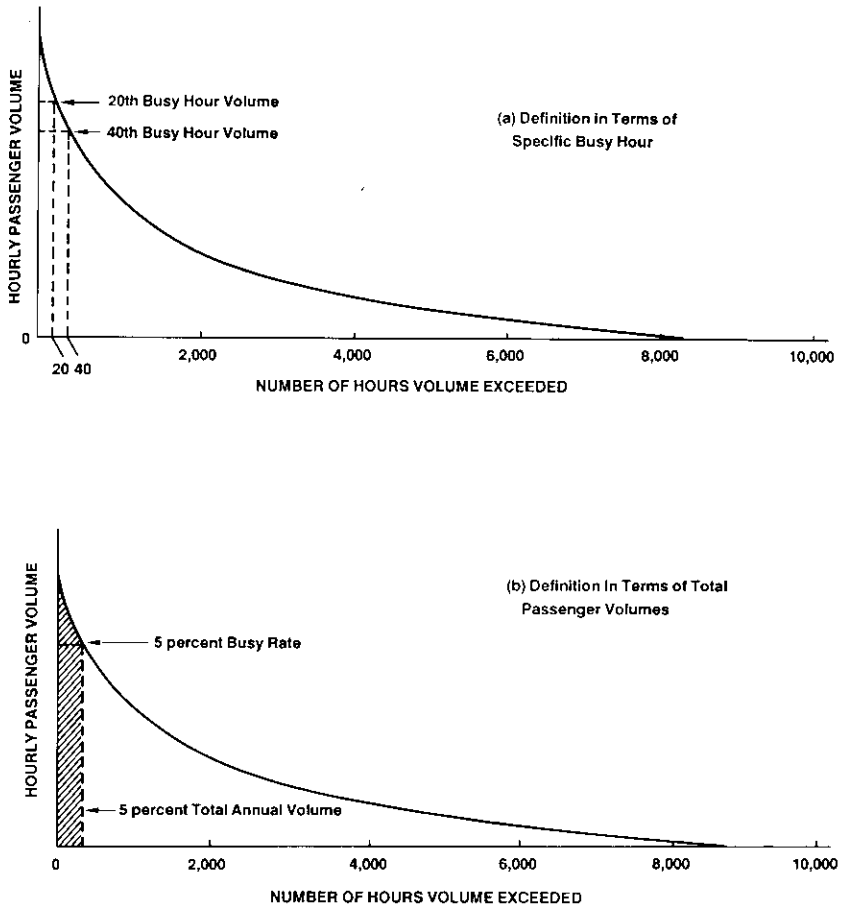


FIGURE 2-8 Alternative definitions of busy hours *(2)*.

with highest passenger traffic, the average-day volume is approximately 3.2 percent (1/31) of the monthly traffic. In the absence of other information, the peak-month average-day peak-hour approach is roughly equivalent to the 20th to 40th busiest hour of traffic, and should give a demand level likely to be exceeded on less than 4 percent of the days in a year (14 to 15 days).

Changing airline route structure, schedules, and aircraft sizes may place peak demand on particular components of the landside at times that differ from one component to another and from those for the airport as a whole. The midday hour when many flights converge at an airline hub-and-spoke center may represent the peak demand for gates and gate lounge areas, whereas at the

same airport, demand at ticket counters and the terminal curb may peak during the 1½ to 2 hr before the scheduled evening departures of several widebody aircraft. Similarly, different airlines may experience peaks at the same airport at different times of day. Because components are linked together, capacity assessment may have to consider more than one analysis period.

NOTES

1. Terms in italics are defined in subsequent paragraphs of this chapter.
2. In Figure 2-4, people begin to arrive faster than they can be served and a queue forms. During the second half of the second hour, the 20th through the 24th passengers are in the queue at the end of the hour.
3. Landside components can operate at maximum throughput for longer periods only if a high demand level is maintained. Under such conditions service levels can always be expected to be poor. In theory the expected passenger delay at the example ticket counter can become infinitely large. As a practical matter, disruptions due to weather conditions and the crush of holiday travel illustrate the extremely low service levels that result when landside facilities are forced to operate at a capacity close to maximum throughput for long periods of time.

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3. *Air Terminal Processing Capacity Evaluation.* Report TP5120E. Airport Services Branch, Transport Canada, Ottawa, Ontario, Canada, Jan. 1986.
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3
Landside Capacity Assessment Process

Landside capacity assessment may address a variety of facilities management, planning, and design problems, as shown by the following examples:

- An airport is experiencing passenger crowding and delay in a terminal building. The airport operator could use landside capacity assessment to identify problems and to judge whether these problems are a result of airline or airport management practices, passenger behavior and demand characteristics, or inadequate facilities.
- An airline wishes to introduce new service at an airport. The airport operator is concerned that this new service cannot be accommodated by existing facilities without severely reducing landside service levels. Landside capacity assessment could be performed to estimate the effect of increased passenger loads on existing facilities and services.
- The community served by an airport is concerned that traffic at the airport will soon grow to exceed the intended capacity of the facility and that service levels will sharply deteriorate. Landside capacity assessment results could be used to provide an objective basis for discussions among government authorities and the community to resolve the conflict.
- An airport intends to add airside facilities. Landside capacity assessment could determine whether additional landside facilities would be required to match the forecast increases in traffic served by the added airside facilities.
- The airlines and the federal government are contemplating new air traffic control procedures that would raise the maximum number of flights that can be handled during one hour by a given airport. Landside capacity assessment

could be used by the airport operator to estimate the implications for landside operations of such expanded airside capacity.

- The federal government must allocate limited funds to achieve the maximum benefit for the air transport system as a whole. Landside capacity assessment could identify airports where federal funds could improve system operations by easing landside constraints.

In each case, landside capacity assessment, a technical procedure, would yield information useful for decision makers. Although landside capacity assessment is only one element among a variety of factors that influence decisions regarding funding and construction of new airport facilities, nevertheless landside capacity assessment may help decision makers understand what the problems are at a particular airport and what potential solutions are available.

Figure 3-1 shows the recommended landside capacity assessment process. Analysts and decision makers can use this process to determine the relationship between service levels and passenger service volumes at a particular airport subject to the demand and operating policies of that airport. This analytical process is the core of landside capacity assessment.

Interaction and feedback among particular steps in the process are critical. Service levels and capacity measures can be assessed only with reference to one another. Performance of any single landside component depends on performance of other components with which that component interacts. Service-level targets set for current conditions may have long-term implications for the airport's future development. Only by successively considering how individual components perform and how they interact with one another and with demand to influence service levels can a meaningful estimate of landside capacity be derived. In this chapter the 11 steps in the landside capacity assessment process are described. Examples of application of the process to the critical landside components are given in Part II.

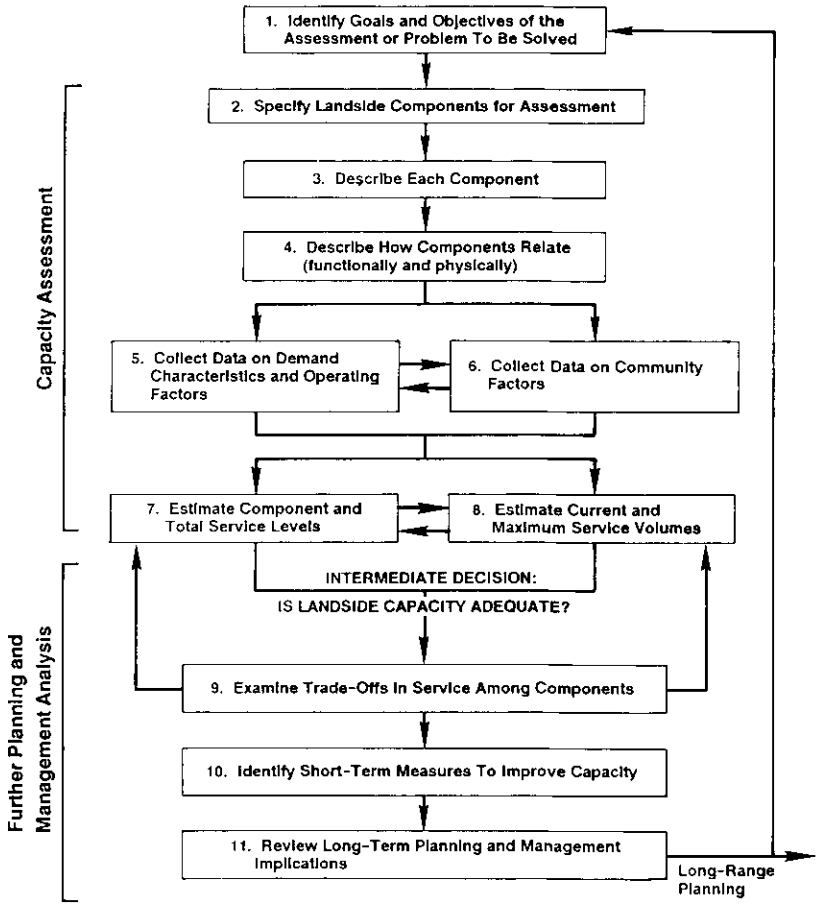

FIGURE 3-1 Landside capacity assessment, management, and planning process.

STEP 1: IDENTIFY GOALS AND OBJECTIVES OF THE ASSESSMENT OR PROBLEM TO BE SOLVED

The reasons for conducting a capacity assessment of all or part of an airport's landside will determine the appropriate scope and level of detail of the analysis. Management and planning problems such as those described earlier or a more general desire to plan for future facilities utilization may lead to application of the landside capacity assessment process. Explicitly identifying the problem or the planning and design goals that motivate the capacity assessment helps to focus the thinking of those who will use the results for making decisions.

As a part of the identification of goals for which an assessment is being made, proposed service-level targets may be set if the various operating characteristics of the components involved are understood. These targets, to be used in determining capacities of landside components in Steps 7 and 8, may be revised or set later when landside capacity estimates are compared

with the projected costs and related consequences of actions to relieve problems.

In each case the interests of all parties concerned with airport capacity should be considered by airport operators. Setting service-level targets is a key part of the assessment process and one in which all parties have an important stake.

STEP 2: SPECIFY LANDSIDE COMPONENTS FOR ASSESSMENT

Assessment should generally focus on components that are experiencing service problems. Although it may often be unnecessary to involve all parts of the airport's landside in an assessment, components linked with the problem components should be included. Normally an assessment is made only for components critical to landside capacity, although in some cases general passenger amenities may be involved. However, before major capital investments are made to solve the capacity problem of one component or group of components, other components should be reviewed to determine what may be the next limiting component.

STEP 3: DESCRIBE EACH COMPONENT

The analyst should describe the facilities and usual operating practices for each component specified in Step 2. In Part II of this report the specific information typically required to assess key landside components is indicated. The characterization should focus on aspects of each component that will remain constant as demand varies, which are addressed in Step 5. If data are unavailable for the airport being studied, analysts may adapt data such as average service rates from comparable airports. Adapting data may expedite the assessment and reduce its cost but will reduce reliability of the results as well.

STEP 4: DESCRIBE HOW COMPONENTS RELATE

The analyst should identify the routes passengers can take through the landside components under study. Is there only one way to pass through the system or are there alternative paths? Are components linked in series or in parallel?

One useful way to show linkage is with a simple diagram of the type shown in Figure 3-2. Components are shown as nodes and passenger paths as the

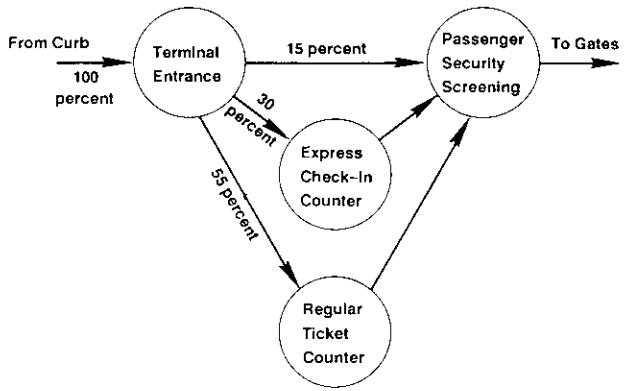

FIGURE 3-2 Example passenger flow link-and-node diagram for ticket counters.

links between nodes. A detailed analysis of a large airport may include hundreds of nodes and links.

Linkages may be in series or in parallel. In series linkage passengers move from one component to another in sequence, and in parallel linkage they choose one of several paths through the landside. For example, in Figure 3-2 the terminal entrance and passenger security screening are linked in series and the express check-in and regular ticket counters are linked in parallel. The number or percentage of passengers using each link in the diagram can be determined by direct observation or estimated from demand characteristics. Figure 3-3 shows another example of how passenger and baggage flows may be charted *(1)*.

The route of any single passenger through the landside is a set of functional components all linked in series. Different passengers with different demand characteristics may use different parallel routes. Airlines often establish components in parallel to tailor their services to major passenger demand groups, such as frequent business travelers and vacationers.

STEP 5: COLLECT DATA ON DEMAND CHARACTERISTICS AND OPERATING FACTORS

The analyst should assemble specific data to describe demand and related operating characteristics for each component of interest. Direct observations at the airport, statistics gathered by the airlines, and analogies from other airports are principal sources of data.

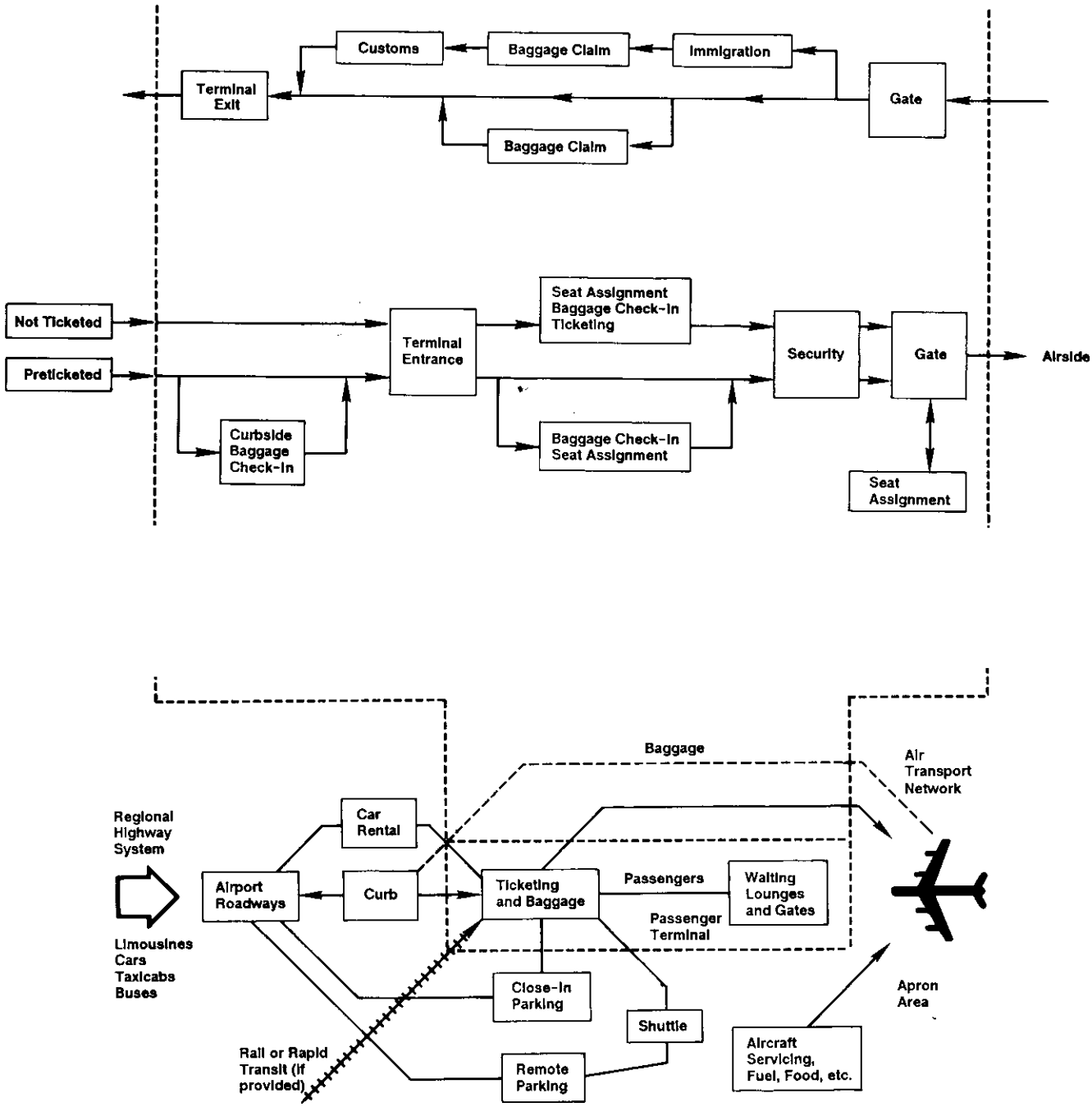

FIGURE 3-3 Typical component linkage diagram *(1)*.

The following types of data are typically required:

- Number and fraction of passengers using each component under review by time of day, with weekly and monthly variations;
- Staffing levels, with employee or agent efficiency (at ticket counters, customs and immigration, etc.) related to per-passenger service times;
- Indicators of overall demand loads, such as number of checked bags per passenger, number of pieces of carry-on luggage per passenger, and number of visitors accompanying each passenger;
- Flight destinations and origins, daily flight schedule, aircraft and likely load factors, gate occupancy times; and
- Fraction of passengers originating or terminating their trips at this airport, distribution of passengers among airlines (transfer and origin or destination), typical times of arrival at the airport versus scheduled flight departure time, and fraction of passengers choosing alternative modes for ground transport.

Architectural or engineering drawings of the terminal building areas of interest are useful to illustrate typical paths of passengers using landside facilities and where capacity problems are occurring. Ramp charts showing representations of daily gate use are also useful to show the daily flight schedule that serves passenger demand on all landside components. Not all of these data are required for all capacity assessments. Analysts normally gather only data relevant to the purpose for which the assessment is being conducted. If the assessment deals with future conditions at the airport, the analyst must forecast demand and component operating characteristics.

STEP 6: COLLECT DATA ON COMMUNITY FACTORS

The analyst should assemble data describing any factors in the local community that influence the demand patterns or operating conditions of the landside components being assessed. These factors typically reflect the current or forthcoming policies, allocations of resources, or sensitivities of local governments and the communities they represent. Thus the data describing the factors may include both specific quantitative and broader qualitative information. Although many of these factors and their influence are difficult to assess, particularly in quantitative terms, their impact can be significant and they should not be neglected in conducting landside capacity assessments.

Community factors influencing capacity at U.S. airports include the following examples:

- Restrictions on aircraft operations, often associated with noise abatement programs, that may influence the type of aircraft using an airport or the hours of their operation. Although data describing existing demand patterns gathered as part of Step 5 will reflect any current restrictions, forecasts of future demand should consider present or possible future policies that may be implemented on behalf of the community.
- The degree of community support an airport can expect to receive as it competes with other public agencies for funds or other public resources needed to permit improvements or expansion. These resources could include funding (such as tax revenues), utilities (such as water or electricity), or access facilities (such as highways).
- Land availability, or an airport operator's expected ability to acquire additional property to permit expansion of apron areas, terminal buildings, access roads, parking, or other landside components.
- Restrictions on vehicular circulation or access routes intended to minimize adverse impacts on adjacent neighborhoods or government-sponsored efforts to promote more efficient methods of travel to airports such as buses, coaches, shared-ride taxis, or shuttles.
- Marketing or promotions, often undertaken by local community business and industry groups, designed to attract new or increased air services or airline passengers, or both (local and distant markets).
- Absolute limits on number of aircraft operations or airline passenger volumes at an airport established by a local government or by an airport operator in response to community desires. In contrast to flight restrictions for noise abatement, these limits may be designed to divert demand to an underutilized facility (e.g., an alternative airport in the region) through landing fees or to suppress demand and thereby reduce the airport's perceived adverse impact on the community.

Further discussion of this step appears in Chapter 4. This data collection and analysis need not duplicate those conducted as part of Step 5, studies conducted for the FAA noise control program ["Part 150" planning (14 CFR 150, 1981)], or other local planning activities.

STEP 7: ESTIMATE COMPONENT AND TOTAL SERVICE LEVELS

Step 7 must proceed in parallel with Step 8. With information gathered in Steps 3–6, direct observation or mathematical modeling may be used to assess service levels encountered by passengers during the analysis period within each component being assessed. To deal with future conditions, projections of demand and operating characteristics, described in Step 5, must be available.

Mathematical modeling is not necessarily complex. Analogies from other airports, statistical correlations, and simple queueing calculations may be adequate. A variety of models that may be useful are surveyed in Appendix B. The reasons for which capacity assessment is being performed determine the level of detail and complexity of analysis, and thus whether mathematical modeling is warranted.

If service-level targets have been set and are being met or exceeded for all components being assessed, the system service level is adequate. However, if service levels for one or more components are below target, the overall system service-level target may still be met or exceeded. For example, delays at the entry to one parking lot may affect a relatively small fraction of passengers and may add a relatively small amount of time to the total landside journey of a departing passenger. The average service level for all originating passengers may be acceptable, even though the parking lot's service level is not.

If some components do not meet targets and no system target has been set, the system service level cannot be defined without consideration of passenger service volumes in Step 8. Feedback and iterative calculations of service volumes and service levels are typically required.

If service levels are lower than desired, higher targets might be set. However, setting service-level targets higher than current service levels implies a willingness to redirect or restrict passenger flows, to change operating procedures, or to invest in new facilities.

STEP 8: ESTIMATE CURRENT AND MAXIMUM SERVICE VOLUMES

Passenger service volumes associated with service levels estimated in Step 7 should be determined. If all service levels of components of interest are exactly on target, these volumes represent the achievable service volume of the system operating as described and subject to the assumed patterns of demand.

If some components are operating at better than target service levels, mathematical models may be used to estimate the additional passenger demand that could be accommodated if service levels were allowed to decline to targets. If service levels are found in Step 7 to be below target, mathematical models may be used to estimate the reductions in passenger volumes that would be needed for service levels to improve to meet targets.

INTERMEDIATE DECISION: IS LANDSIDE CAPACITY ADEQUATE?

In many cases, completion of Steps 2–8 will produce enough information about current and target service levels and associated current and achievable passenger service volumes to answer the questions raised in Step 1. A judgment whether landside capacity is adequate to meet demand can be made for the purposes that motivated the assessment.

If it appears that landside capacity is insufficient—if service levels are below target—additional analyses should be undertaken to explore ways of making better use of the landside components in question and to identify what changes in system configuration, operations, or demand may be required to increase achievable service volumes or improve service levels. These additional analyses are not an immediate part of the capacity assessment, but rather are part of the management and planning context within which landside capacity assessment occurs.

STEP 9: EXAMINE TRADE-OFFS IN SERVICE AMONG COMPONENTS

If some components in the assessment exhibit service levels above target and others are below target, the performance of the poorer-performing components might be improved by shifting patterns of demand or operating characteristics of other components, recognizing that some declines in service levels in the higher-performing components may be acceptable to achieve smoother operations overall. Such trade-offs among components obtain more generally satisfactory service levels through a closer match between demand and capacity, which means higher efficiency and better overall system performance. Overall system demand, a result of flight schedules and passengers' choices about time of arrival at and departure from the airport, is at this step of the assessment considered fixed.

STEP 10: IDENTIFY SHORT-TERM MEASURES TO IMPROVE CAPACITY

Short-term actions to improve capacity generally preclude any major construction or substantial restructuring of leases and financial arrangements. Such actions might include encouraging airlines to adjust flight schedules or staffing policies or changing gate operation strategy if airlines involved in the assessment process agree on the need. Otherwise, airport operators may be limited to actions that involve only those areas of the landside fully under their control.

Sometimes short-term actions may offer temporary relief for a problem while more permanent solutions are being devised. For example, if existing

baggage-claim and gate lounge areas are adequate to serve the growth in passenger loads, remote parking of aircraft and use of transporter vehicles may increase effective gate capacity while additional gates are being constructed to accommodate proposed new airline services.

STEP 11: REVIEW LONG-TERM PLANNING AND MANAGEMENT IMPLICATIONS

Landside capacity assessment is not a substitute for long-range facilities planning, although it is an important element in developing or revising an airport master plan. The long-term implications of the analyses conducted in Steps 1–10 may include development of new facilities, institution of major changes in operating practices at existing facilities, and shifts in policy regarding growth of airport activity. These implications must be considered within the context of the goals and objectives stated in Step 1.

If immediate landside capacity problems motivate the assessment, the airport operator and airlines using the airport may be able, working together, to devise solutions to the problems. If future changes in traffic threaten to raise problems where they do not now exist, early recognition of the financial and community impacts of solutions to these problems will aid those making difficult decisions about airline fleet management and investments in airport and community facilities. In both cases, feedback within the landside capacity assessment process may lead to reconsideration of basic goals and expectations about landside service levels and eventual agreement among all parties that problems are well understood and that the proposed solutions are reasonable.

REFERENCE

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4
Community Factors

Airports, often among the largest (in terms of total land area) and most important single public facilities located in a metropolitan area, contribute to the well being of the communities they serve in a variety of ways. They provide access to national and international air transportation systems and employ substantial numbers of people directly and many others indirectly in industries that depend on good air transport service. Land values may rise because of the airport's presence, and businesses may be attracted to invest in regions with good air service.

But at the same time, airports can be of concern to their neighbors because of aircraft noise and road traffic congestion. In addition, an airport may occasionally compete for municipal services that are in short supply within the community, such as water and power supplies and police and fire protection.

In broad terms, the airport-related community has three principal segments: airport users (travelers and shippers and other businesses that depend on air transport and their employees), residential and commercial neighbors of the airport, and local and state government. This airport-related community together with airport operators, airlines, and the FAA determine how an airport will develop and operate.

An airport's long-term ability to match growth in air travel demand with adequate capacity to serve that demand often depends on the perceived balance between the benefits and the problems associated with the airport. When this balance is very favorable, the airport operator typically has relative freedom in directing the airport's operation and growth. However, if a community or key parts of the community perceive that the problems raised by an airport outweigh the benefits, the community may seek to restrict the airport's ability to expand or to operate efficiently. The restrictions imposed may curtail construction of new airport facilities, control aircraft operations, or limit land

and municipal services available to the airport. Through such restrictions the community may influence airport capacity.

When an airport's contribution to the community is viewed favorably, landside capacity may be expanded to encourage future growth of demand. San Francisco International, for example, has built new terminal buildings and access roads, and the Port Authority of New York and New Jersey is preparing to renovate and expand terminal buildings at John F. Kennedy International to regain service levels consistent with that airport's role as the principal gateway for foreign visitors to the United States. In such cases, inconvenience during construction and longer-term trends of traffic growth are tolerated by the community.

In an assessment of any airport's landside capacity, the potential impact of community factors must be recognized, particularly when these factors may constrain the airport's ability to meet demand. How restrictions may come about, the types of restrictions that may be imposed, and how to assess the impact of such restrictions on capacity are reviewed here.

SOURCES OF CONCERN

Most of the nation's airports have been in operation for many years at locations established when the metropolitan areas served were considerably smaller than they are today. Few of these airports were expected to meet the needs of today's jet aircraft or the wide range of passenger and cargo services now offered by the industry.

Some of these airports—Logan Airport in Boston; National Airport in Washington, D.C.; and Lindburgh Field in San Diego—are close to downtown city centers. New high-rise buildings and changing population characteristics have led to increasing conflicts between these airports and their respective communities. Even newer airports such as Dallas-Ft. Worth International and Dulles International near Washington, D.C., built on large sites in seemingly remote locations, now experience the problems of increasing suburban growth in areas exposed to aircraft noise and increasing highway congestion. Although the benefits of improved air transportation access and efficiency are distributed generally throughout the region an airport serves, the associated problems are largely concentrated in the immediate vicinity of the airport *(1)*.

Noise

Aircraft noise is the most frequent cause of organized community efforts to influence airport operations. As a consequence, aircraft-related noise issues

provide good illustrations of how community factors may affect airport capacity. For example, the Airport Access Task Force reported to Congress in 1983 that at least 44 of the nation's 50 busiest airports (in terms of annual number of passenger enplanements) had imposed operational restrictions to control community noise exposure *(2)*.

Although cases involving damage claims based on aircraft noise appeared in the courts much earlier, national policy toward aircraft noise began to take shape in 1968 when Congress amended the Federal Aviation Act of 1958, requiring that national regulations for aircraft noise control be established and giving FAA the responsibility for developing these regulations *(3)*. With passage of the National Environmental Policy Act of 1969 (NEPA), Congress further required that assessments be made of significant environmental impacts likely to result from major federal government actions such as participation in airport development. The 1968 aviation act amendment addressed control of noise at its source, that is, at the aircraft, but NEPA emphasized a need to try to ensure compatibility of airports and their surroundings. Subsequent laws, regulations, and guidelines at federal, state, and local levels have built on these two bases—control at the source and compatibility with the surroundings.

Since 1969 FAA standards have set allowable noise emissions for new aircraft operated in the United States. As newer aircraft meeting the most recent and stringent of these standards [termed "Stage 3" aircraft under the regulations *(4)*] enter the commercial airline fleet, and as older aircraft are retired or retrofitted to meet the more stringent standards, aircraft noise around airports is expected to decline significantly. However, retirement of all noisier aircraft may not be complete until after the year 2005 *(2, 5)*.

In the meantime, some communities have established regulations restricting operations by aircraft not meeting Stage 3 standards. In Boston and at Washington's National Airport, for example, these restrictions prohibit nighttime operations by other than Stage 3 aircraft.[1] Because airlines and cargo shippers serving such airports do not yet operate aircraft that are both appropriate to the types of service desired and compatible with these noise standards, their ability to schedule flights may be severely curtailed by this type of restriction. Other types of restrictions, such as establishing preferential runway use and flight paths, may have a less drastic impact on airline operations but still affect capacity by reducing the number of operations that can be handled at the airport. Some communities have tried to restrict all types of jet aircraft *(2)*.

Federally sponsored programs of local land use planning encourage compatibility between airports and their surroundings. [The current program is termed "Part 150" planning because of its basis in this part of the Federal Aviation Regulations *(6)*.] The thrust of these programs is toward controlling

types and intensity of land use in areas likely to be exposed to aircraft noise, but enforcement of controls is a local concern and strictly voluntary. Even when local government officials involved in the planning are committed to land use control, later administrations may find the advantages of new development more attractive than the possibility of avoiding yet-to-be-realized noise conflicts. Residents in such newly developed areas then may become leading proponents of restrictions on aircraft operations and airport development.

Other Sources

Aircraft noise is not the only source of community concern. Others include road congestion and associated environmental degradation, competing demands on community resources, and limitations on land availability.

Many highways serving airports also serve the general travel needs of the surrounding community. Growth of traffic on these highways leads to congestion, and both groups of users suffer. Congestion on major highways may also spill over into local streets, with significant impact on residential neighborhoods. This congestion is typically accompanied by automobile air pollution, noise, and perceived safety problems. Restricting air passenger growth is one way to curtail further highway traffic growth. For example, persistent congestion on the San Diego Freeway, a principal entry to Los Angeles International, is cited as a reason for imposing a limit on the annual number of passengers at the airport (*7*, pp. 83–88). In Boston management of Logan Airport is working with highway agencies to find ways to relieve the serious congestion in the two tunnels that are the main link between downtown and the airport. Construction of a third tunnel is a high priority for solving the problem. In each case future growth of the airport may be restricted, and although present demands are met, service levels on the highways are very low during busy periods.

In communities where basic resources are scarce or where funds to develop infrastructure are limited, an airport may find itself competing with other parts of the community for municipal services. Apparent lack of adequate water supplies threatened to stall plans for Denver's proposed new airport. Lack of power supplies delayed facilities development at Oakland International. Sewage and solid waste disposal are recurring problems at some airports. Cooperation of several political jurisdictions is often required to solve these problems, which may be hampered when voters choose not to endorse bond issues or authorizing referenda. Again, current demands are served, but future expansion may be limited. If demands grow, service levels are likely to decline.

Airports with relatively small land areas typically have limited capacity. For example, National Airport in Washington, D.C., and La Guardia in New York City are able to serve large volumes of traffic because a large fraction of their aircraft operations can occur over water. Although airports such as Hartford's Brainard Field, Detroit's older City Airport, and Cincinnati's Lunken Field are no longer in commercial service, they serve other aviation needs and there is not enough space for new facilities—the airport is surrounded by developed land or physical barriers. At other airports the cost of land or the community's attitude toward airport development has a similar effect. In Carlsbad, California, airport expansion is prohibited by local ordinance *(8)*. Such restrictions could influence the ability of these airports to meet future demands for new commercial services.

Development of new airports within practical distance of downtown districts has become virtually impossible in most major metropolitan areas because of suburban growth. The search for a site for a fourth jetport to serve the New York City metropolitan area has been ongoing for three decades *(9)*. This inability to develop new airports may tend to increase the pressures of growth in passenger demand at existing airports.

TYPES OF RESTRICTIONS

Potential community-imposed restrictions on airport facilities and services fall into two principal categories:

- Policies that prevent expansion of existing airport facilities or development of new airports. Such policies may include delays in financing or approving airport expansion plans or related highway projects and local zoning that encourage incompatible development of land near the airport.
- Regulations that curtail or alter permissible aircraft operations. Such regulations may include limits on number of daily aircraft operations, time of day when operations are permitted, operations by particular types of aircraft, and flight paths.

Restrictions in the first category can apply to both airside and landside, affecting taxiways, runways, parking structures, rental-car terminals, cargo handling facilities, or fuel storage tanks. Permit and license requirements may make airport expansions prohibitively expensive, and as shown by the history of the plans for New York City's John F. Kennedy International, environmental impact review procedures can be used to halt particular projects *(9)*. The threat of protracted litigation may also discourage planning for expansion to meet air transport demand.

Refusals to provide facilities and implement policies supporting airport growth may permit general urban growth to encroach on the airport and lead to loss of potential capacity. The city of Alexandria, Virginia, surrounding much of the Washington, D.C., National Airport, views the airport as an inappropriate use of valuable—and taxable—urban land and continues to support residential and commercial development within noise-exposed areas. The constituency supporting more stringent airport restrictions thus continues to grow. At Dallas-Ft. Worth International and at Washington's Dulles International, new land development around the airports raises the prospect that planned future runways will never be operated at maximum capacity because the airport's neighbors, who were not there when the airports were planned and built, will successfully impose restrictions.

Restrictions in the second category, aircraft operations, sometimes take the form of nighttime curfews, perhaps on aircraft not qualifying under the FAA's noise emission standards, or requirements that pilots follow special flight paths and noise abatement procedures on landing and takeoff. At New York City's John F. Kennedy International and Boston's Logan, flight operations are directed to particular runways, which are changed from time to time to avoid exposure of any one area to an excessive share of aircraft noise. In Los Angeles restrictions are established in navigational easements that the airport has had to purchase from individual owners of nearby property. In some cases the threat of litigation may motivate the airport operation to avoid serving certain types of aircraft.

Some communities have tried to restrict operations strictly on the basis of inadequacy of landside facilities. In Westchester County, New York, and at Southern California's John Wayne Airport in Orange County, airlines, airport operators, and the community reached out-of-court settlements to limit the number of flights serving these airports.

ASSESSING COMMUNITY FACTORS

Likely community effects on airport capacity may be assessed in two steps:

- Estimate the possibility that the community will impose additional restrictions on airport operations and growth, and
- Estimate the effect of restrictions, both those now in place and those possibly to be imposed in the future, on service volumes.

Both steps depend on judgment of social, economic, and political conditions within the community rather than on well-defined analytical models and analysis procedures. Assessment is more a matter of recognizing significant factors than collecting and analyzing detailed data on facilities and operations.

Possibility of Restrictions

Committee members' experience suggests that several characteristics of the community can increase the possibility that airport restrictions may be imposed:

- The land area of the airport is small compared with the number of operations or enplanements served. In such cases, airport growth is more likely to create a need for new land and infrastructure.
- The land area and number of people exposed to aircraft noise are large compared with the number of operations or enplanements served. Data gathered from selected planning studies prepared under FAA noise control programs, summarized in Table 4-1 and Figures 4-1 and 4-2, demonstrate the

TABLE 4-1 ACTIVITY LEVELS AND ESTIMATED NOISE EXPOSURE AT SELECTED AIRPORTS

	Activity Level			Noise Exposure[a]	
Airport	Annual Airport Operations (thousands)	Annual Passenger Enplanements (thousands)	Airport Grounds (acres)	Land Area (acres)	Residential Population
Monterey, Calif.	94	212	496	1,024	972
Providence, R.I.	180	496	974	1,920	8,984
Islip, N.Y.	231	414	1,350	2,749	NA[b]
Baton Rouge, La.	151	327	1,094	3,430	8,900
Sarasota-Bradenton, Fla.	155	696	1,194	6,010	12,900
Cleveland, Ohio	208	2,932	1,600	9,638	28,730
Portland, Oreg.	204	2,396	3,205	13,696	NA
Denver, Colo.	468	13,494	4,651	20,200	34,000[c]
Pittsburgh, Pa.	296	6,699	10,200	26,240	NA
Atlanta, Ga.	566	19,610	3,753	31,104	81,188
Seattle-Tacoma, Wash.	212	5,643	2,000	31,232	NA
Chicago (O'Hare), Ill.	592	20,761	6,795	51,277	285,430
Casper, Wyo.	88	111	4,500	900	NA
Jackson, Wyo.	37	62	764	430	25
Scottsdale, Ariz.	162	3	NA	403	NA
Groton, Conn.	20	71	434	263	24
Lebanon, N.H.	5	35	390	16	NA

[a]Area and population where projected noise is above L_{dn} = 65 dBA.
[b]NA = not available in plan or study reviewed.
[c]Estimated by staff of Stapleton Airport.
SOURCE: Part 150 plans prepared by airport management; Airport Operators Council International survey; FAA, National Plan of Integrated Airport Systems. Data are for 1984.

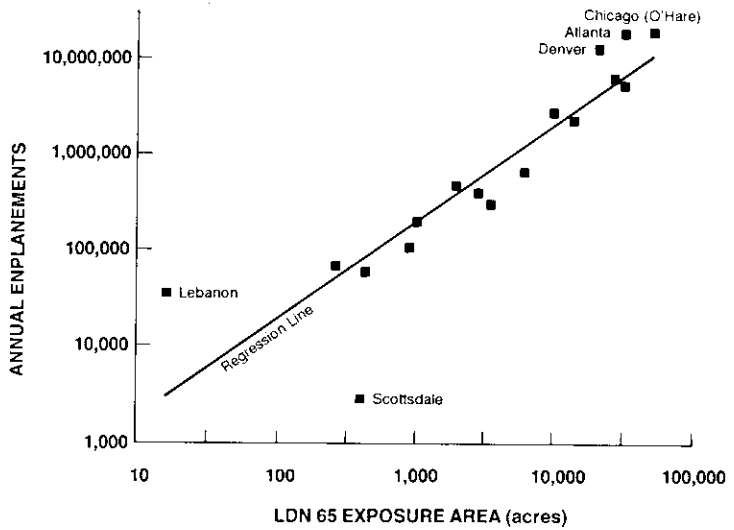

FIGURE 4-1 Enplanements versus noise-exposed area in 1984 at selected airports (logarithmic scales).

past relationship between number of air passengers and noise-exposed neighbors at selected airports.[2] These indirect relationships may change as new aircraft are introduced and as population shifts within metropolitan areas, but may be useful in judging whether an airport is within the range of typical experience.

- Airport neighbors include substantial numbers of those likely to be both particularly sensitive to an airport's noise and other adverse impacts and vocal in their opposition to these impacts. In general, wealthy, elderly, and highly educated populations may be more likely to complain and to take political or legal action against the airport.
- There is a history of adverse community response and resistance to airport activities. Such a history may be evidence of a relative probability of restrictions.
- The airport operator has failed to encourage cooperation and reasonable recognition in the community of the need for a balance of airport benefits and costs. Such diverse airports as those in Burbank, California, and in Tampa, Florida, have demonstrated how good communications and cooperation with the community can help to resolve community concerns.

The presence of any of these characteristics in the community may indicate a relatively greater possibility that service volumes achievable at the airport

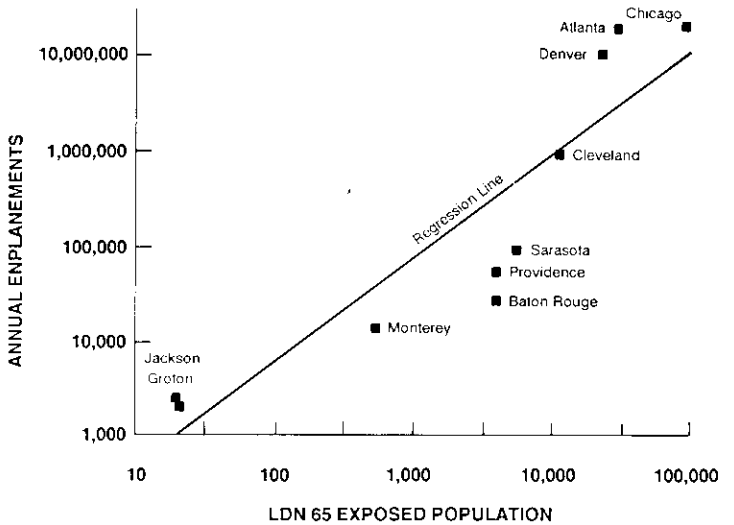

FIGURE 4-2 Enplanements versus noise-exposed population in 1984 at selected airports (logarithmic scales).

may be reduced by community-imposed restrictions. The analyst should then proceed to estimate how large the reduction will be.

Effect on Capacity

To estimate how much community-imposed restrictions may reduce service volume, the analyst must both assume what form restrictions will take and project what service volumes and service levels will be with and without these restrictions. Assumptions about the form of restrictions may be based on comparisons with other airports in similar community situations. If aircraft noise complaints from neighbors are the most likely source of constraints, experience suggests that restrictions on flight operations are possible. If lack of land use control in the areas around the airport is a problem, restrictions on facilities expansion as well as flight operations may occur. The analyst should state explicitly the restrictions assumed and the rationale for the assumption.

Community-imposed restrictions may affect service volumes and service levels in two ways. First, by preventing expansion of facilities to match passenger growth, they can lead to lower service levels as service volumes increase. Second, by curtailing operations they shift demand to different time periods and perhaps restrict total demand, thereby changing service volumes

and service levels.[3] In either case, the appropriate analysis period will be a full operating day, month, or year. Estimates of decreases in potential service volumes may be based on calculated average unit service volumes achieved at the airport (e.g., passengers per unit time per gate, per unit floor area, per parking space, or per acre of airport land) with and without the restrictions. Comparisons with unit service volume indicators at similar airports may also be useful.

The assessment should consider how airlines and the airport may respond to constraints. Airlines may introduce new aircraft rather than cancel scheduled flights or use ticket pricing to shift demand from constrained times to other periods. Faced with declining service levels on access highways, the airport may encourage increased passenger use of transit services, thereby changing both service volumes and service levels.

NOTES

1. Restrictions may have no direct impact on landside operations during the busy periods of a day, but nevertheless influence landside capacity by limiting when flights can operate or how many flights can be accommodated at particular times.
2. *Ldn*, the "day-night" weighted sound pressure level, is a composite measure of cumulative aircraft noise exposure that takes into account the intensity, frequency, and time of day of individual aircraft noise events. *Ldn* is expressed in decibels (dB). An increase of 3 dB represents a doubling of the perceived severity of noise exposure. A penalty of 10 dB is applied to the noise generated by flights operating during nighttime hours. The FAA has adopted *Ldn* as the best indicator of noise exposure and uses it as a basis for recommending what types of land use are compatible with anticipated levels of aircraft noise exposure. Areas where the forecast *Ldn* level is less than 65 dB are presumed to be suitable for any type of land use.
3. Restrictions may have no direct impact on landside operations during the busy periods of a day but nevertheless influence landside capacity. For example, prohibition of nighttime operations in principle will shift passengers into the daytime peak period, raising service volumes and reducing service levels. However, some fraction of the demand that might be served by nighttime operations will simply not develop. This effect on capacity is most important at airports serving air cargo and long-distance flight operations for which daytime arrivals are difficult to schedule.

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3. *Guidance Notebooks for Environmental Assessment of Airport Development Projects*. Report DOT P5600.5. U.S. Department of Transportation, 1978.

4. *FAA Noise Control and Compatibility Planning for Airports*. Advisory Circular 150/5020-1. Federal Aviation Administration, U.S. Department of Transportation, Aug. 5, 1983.
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5
Research Needs

The process and guidelines recommended in this study are an important first step toward developing consistent nationwide procedures for assessing airport landside capacity. Substantial research will be needed before this first step will lead to definitive airport landside capacity assessment guidelines and standards. The Transportation Research Board's widely used *Highway Capacity Manual*, an evolutionary product of more than 30 years and millions of dollars of research, is evidence that no single study can achieve this goal.[1]

Current quantitative knowledge about landside operations and service levels is poorly developed. Reliable comparative statistics on operating conditions in airports are scarce. Mathematical models useful in forecasting landside service conditions are frequently proprietary and not available for public use. Airline staffing and space utilization statistics are often not available. What airline passengers may want and be willing to pay for is frequently a matter of conjecture, except perhaps where airline and airport market research has been conducted to shed light on specific problems. The gaps in knowledge can be filled only by a purposeful and coordinated research program.

In particular, four major topics warrant immediate attention by the FAA, airlines, and airport operators:

1. Collection of comparable and detailed data on passenger behavior and facilities utilization at a broad cross section of commercial service airports should be undertaken. Such data will give a sound basis for defining service-level measures. The Canadian Airport System Evaluation (CASE), a method and program for such data collection in Canadian airports, is a potentially useful model of what might be done in the United States. The CASE program

is one of the data collection activities that has supported Canada's substantial progress in assessing airport landside capacity and maintaining balanced use of airport facilities.

2. Data on aircraft delay because of landside problems should be collected in a format compatible with that for airside delay. Major investment decisions are considered for airside facilities without adequate information on landside consequences. For example, new air traffic control instruments and procedures may permit a significantly greater number of aircraft operations to occur within a peak hour but may substantially increase loads on landside facilities. However, current information provides a very limited basis for weighing the relative costs and benefits of such a change to the air transport system as a whole.

3. There should be continuing refinement and documentation of measures and procedures for landside capacity assessment. The work presented here is necessarily limited by the complexity of the airport landside and by the resources and time available. More meaningful guidelines for landside capacity assessment can be developed by building on this base, which will yield substantial benefits of improved resource utilization throughout the aviation industry.

4. Testing and validation of the assessment process presented here are required. Precedents for this process exist, most notably in the work of several consultant organizations and the CASE program. Nevertheless, there is limited experience with landside capacity assessment within the comprehensive context described here. Data collection and setting of service-level targets for an assessment may prove challenging. Test cases at several airports would be useful to demonstrate the value of and problems with this landside capacity assessment process. These pilot assessments would sharpen understanding of community influence as well as airline and passenger demand characteristics in landside capacity measurement.

Major barriers to establishing a research program directed toward landside capacity are institutional and financial. No single agency or organization is responsible. Although the FAA maintains a nationwide scope of interest, it has very limited responsibilities for landside development and management. National professional and trade organizations depend on contributions from their membership for their support and can sponsor few research activities. Few individual airports can afford their own major research programs. In the absence of a single agency with clear responsibility in this area, it is recommended that FAA take the research lead, working with airports to develop a specific institutional, management, and financial plan for airport landside research.

NOTE

1. The *Highway Capacity Manual* may be a useful model of what might be achieved for airport landside capacity assessment, and several of the principles asserted in this report are related to those applied in highway assessment and planning. However, the Manual is directly relevant to only a few elements of the airport landside.

Part II
Assessing Capacity and Service Levels of Functional Components

Terminal landside service levels and capacity are controlled by the behavior of individual functional components and interactions among components. Most capacity assessments begin with consideration of only a portion of an airport's landside, that is, a few problem components. In such cases the analyst need not apply the process described in Part I to the entire airport.

In Chapters 6-16, guidance is presented for applying the landside capacity assessment process to the following potentially critical components: Chapter 6, aircraft parking position and gate; Chapter 7, passenger waiting area; Chapter 8, passenger security screening; Chapter 9, terminal circulation (corridors, stairs, etc.); Chapter 10, ticket counter and baggage check; Chapter 11, terminal curb; Chapter 12, parking area; Chapter 13, ground access; Chapter 14, baggage claim; Chapter 15, customs and immigration, and Chapter 16, connecting passenger transfer. In the concluding chapter, interactions among groups of such components and the landside system as a whole are considered.

Each chapter is structured as follows:

- *Description* of the component, where its boundaries may normally be drawn for assessment, and the demand and operating factors generally influencing that component's service level and capacity.
- Discussion of the *demand patterns* that the component must typically accommodate, particularly the peaking conditions likely to give rise to service-level and capacity problems. Where relevant data are available, typical examples of demand variations are discussed.

- Description of the *operating characteristics* typical of the component, such as airline staffing practices and processing rate variations, that influence component utilization and effectiveness. Where relevant data are available, typical examples of service conditions and component operating performance are discussed.
- Review of *analysis tools and assessment standards* found in the literature and current practice to assist in assessing component capacity and levels of service. A selection of available analysis tools is reviewed in Appendix B. Information from the literature that may help in setting service-level targets is cited.
- An *example of the assessment process* to demonstrate how data gathered for a particular airport may be used to estimate achievable service volume based on a specific pattern of demand and service-level target.
- A brief discussion of specific *research needs* related to capacity assessment for the component. These research needs supplement the more general recommendations in Chapter 5.

6
Aircraft Parking Position and Gate

When a commercial service aircraft arrives at the airport, it maneuvers from the runway system to the taxiway system and to the ramp area adjacent to the terminal building. This ramp or apron area contains the aircraft parking positions—the designated locations where these aircraft unload and load passengers and baggage and are serviced—and the gates through which passengers pass to board or leave an aircraft. In being routed to its assigned parking position and gate, the aircraft may encounter other taxiing aircraft and ground traffic, may have to wait for its assigned gate to be vacated by another departing flight, and in congested or geometrically constrained apron areas may have to be towed into the parking position. If the parking position is remote from the terminal building, passengers may have to walk some distance on the ramp to reach the terminal or may be carried by transporter vehicles. After an aircraft has been serviced and loaded and has departed, ground crews may need time to prepare the position before the next arrival can be handled.

The various activities of arrival and departure combine with facilities characteristics to determine the number of flights that the gate complex can accommodate in a period of time and the delays to which passengers and aircraft may be exposed. In addition, gate operations influence passenger demand characteristics and thus service levels throughout the airport landside.

DESCRIPTION

Aircraft parking positions are designed to accommodate the particular dimensions of specific types of aircraft and may thus be unavailable to other aircraft with significantly different dimensions. If the apron area is not large enough to

allow safe maneuvering of aircraft under established FAA, airline, and airport standards, capacity may be constrained. If a parking position is not available at the terminal building, the aircraft may be accommodated at a hardstand, an apron parking position made relatively permanent by installation of ground power and sometimes fueling facilities. During periods of very high demand, commercial service aircraft may have to be parked and serviced at remote parking positions.

Although airlines typically lease gates, they may own the passenger loading bridge and aircraft service equipment installed at the gates. These aircraft gates may be operated on an exclusive-use basis, under which a single airline has complete use and control of a gate. Lease agreements may give the airport operator the right to renegotiate for underutilized gates, but day-to-day assignment of aircraft to gates under the exclusive-use arrangement is usually an airline decision. Because of differences in schedules, a flight may arrive to find all of its company's gates occupied and have to wait for gate access, even though the nearby gates of another airline with a different pattern of arrivals are empty.

Some airports provide preferential and joint-use gate strategies. Under the preferential gate use strategy, a gate is leased to a particular airline but the airport operator retains the right to assign it to other airlines when it is not in use by the leasing airline. Under the joint-use gate strategy, gates are usually rented to more than one airline. This strategy is similar to exclusive use in that the airport operator is not typically involved in day-to-day gate assignment decisions. Except where very large numbers of daily flight operations occur, gates operated under preferential and joint-use strategies normally serve more flights than gates operated under an exclusive gate use strategy.

Some airports normally operate gates on a common-use basis, in which the assignment of aircraft to gates is entirely an airport operator's decision. This type of operation is common at small commercial service airports.

Beyond the required basic physical compatibility between each airline's aircraft fleet and an airport's gates, hardstands, and remote temporary apron parking locations, the principal measure of service level for aircraft parking positions and gates is the time an aircraft and its passengers may be delayed by gate area congestion. Although data on aircraft delays due to airside problems are available, information on delay due to landside problems such as gate access or departure-gate holds is not. Such data are needed to define service levels. Some airport professionals believe that apron configuration is one of the principal characteristics influencing airport landside capacity.

Demand and operating factors influencing service level and capacity of aircraft parking positions and gates are given in Table 6-1. Because of typical gate service or turnaround time, capacity over the short term, normally a period of 0.5 to 2 hr, is typically one aircraft per parking position and gate.

TABLE 6-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF AIRCRAFT PARKING POSITIONS AND GATES

Factor	Description
Number of parking positions and physical layout	Controls the total number of aircraft at gate at one time, should include hardstands and apron parking
Utilization	Ratio of time gate is effectively occupied (service, layover, and recovery) to total service time available (hours of operation), depends on flight turnaround time, including time for recycling between successive flight operations (a function of aircraft type and airline scheduling practices)
Hours of operation (especially noise restrictions)	Limits number of operations that can be handled per gate in a given day
Flight schedule and aircraft mix	Determines whether gates are likely to be available when needed, taking into account uncertainty in actual operation times compared with schedule; gates must be physically compatible with type of aircraft scheduled (see Utilization)
Airline leases and operating practices, airport management practice	Gate use strategy (see text) controls gate availability and utilization

However, 100 percent gate utilization may not be achievable because of incompatibility between parking and ramp configuration or gate equipment and types of aircraft seeking access. Over the course of a full operating day, the patterns of arrivals and departures as well as airline ground operations, community factors, and weather determine the average number of operations per gate that can be served over the course of a year and whether a group of gates can accommodate additional flights.

DEMAND PATTERNS

The demand for aircraft gates or other aircraft parking positions is determined primarily by the flight schedule for the airport, including what type of aircraft is used for each flight. This demand may be influenced by external factors such as weather and airfield and airspace conditions.

A ramp chart such as that in Figure 6-1 is often used to show the schedule. The scheduled gate service or turnaround time, which is the time between the arrival of a flight at the gate and availability of the gate for another arrival, is given for each aircraft. Airline operating practices affect turnaround times

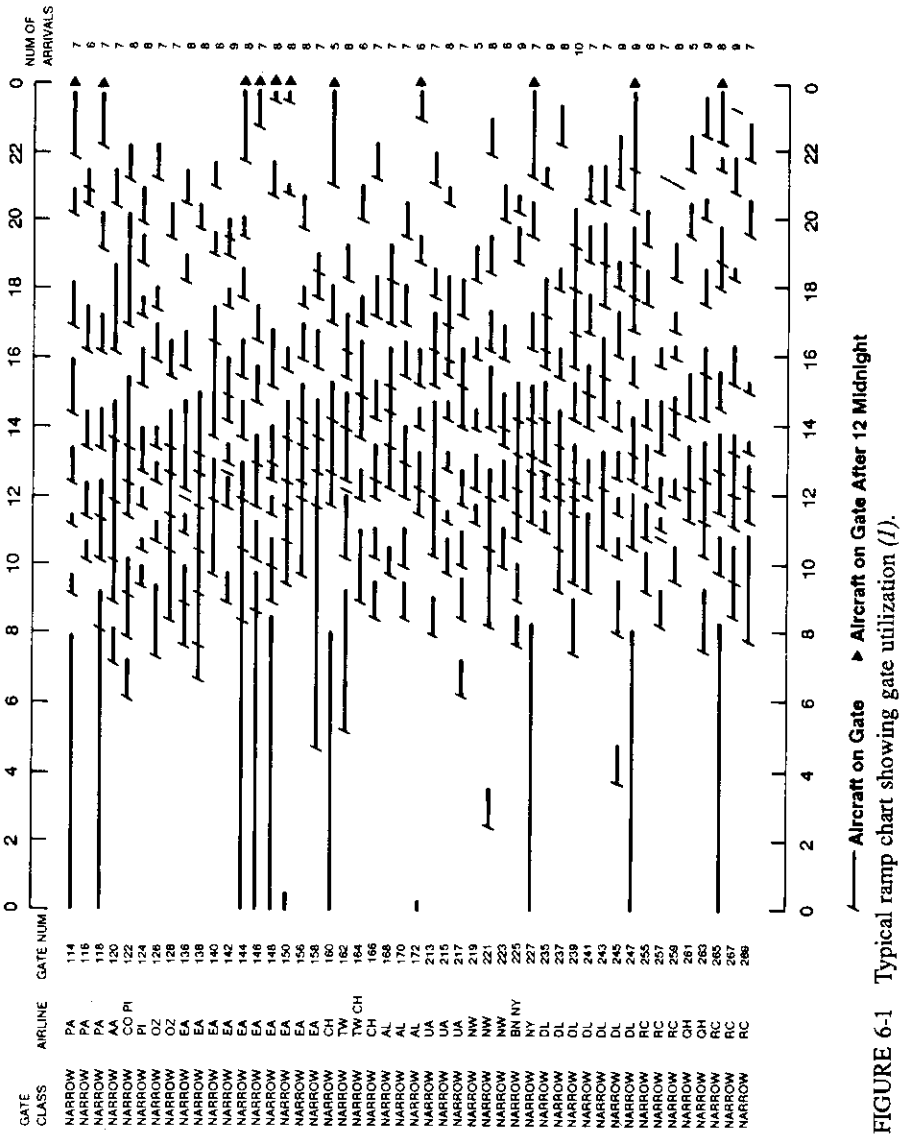

FIGURE 6-1 Typical ramp chart showing gate utilization *(1)*.

TABLE 6-2 TYPICAL GATE TURNAROUND TIMES FOR COMMERCIAL SERVICE AIRCRAFT *(2, 3)*

Flight Type	Typical Aircraft	Turnaround Time[a] (min)
Long range, particularly international	Jumbo jet (B-747, DC-10, L-1011)	60-150
Medium to long range	Long-range jet (B-767, DC-9)	45-90
Short to medium range	Short-range, high-payload jet, turboprop (A-300, B-727, DASH 7)	25-60
Short-range, commuter	Smaller prop, turboprop jet (Shorts 330-200, F-27, Gulfstream II)	20-45

[a]Includes gate occupancy and recycle time. Times for continuing flights on medium- to long-haul routes may be shorter.

within the broad range associated with each type of aircraft. One of the more important factors in the determination of gate service time at a particular airport is whether the aircraft is making a stop en route or the flight is terminating at that airport. Gate service time is usually longer if the flight is terminating.

Typical gate turnaround times for a range of aircraft and flight types (Table 6-2) become longer as flight distance and passenger load increase because more time is required for refueling, cargo and baggage loading, and aircraft service. Typical times are published by aircraft manufacturers for the various aircraft, but in practice these times vary considerably, depending on the nature of a particular airline operation at a particular airport.

An alternative way of specifying gate service time is the average time that the aircraft actually occupies a gate and the average utilization of that gate over the period of analysis. Average gate utilization is normally no more than about 70 percent at most U.S. airports even during peak periods *(2)*.

At the simplest level, the demand for gates can be expressed as the total time that gate space is required, which is the sum of the service or turnaround times for all flights. This total time cannot exceed the product of the number of gates and the number of available operating hours in a day. The theoretical maximum throughput capacity of a series of gates at the airport is the total gate time supplied divided by the scheduled average gate occupancy time at the airport.

In practice, the various factors influencing gate capacity may cause the actual number of flights handled to be less than this theoretical capacity. Actual schedules of individual flight operations are very significant in determining actual gate capacity. A ramp chart (Figure 6-1) shows this actual schedule, including scheduled gate occupancy times.

Many airports exhibit a pattern of flight operations that has two or three demand peaks—typically morning and late afternoon "rush hours" and perhaps a midday peak. During these periods all gates may be occupied for busier

airlines. At other times many gates may be vacant. Even during off-peak times for the airport as a whole, an individual airline may experience "gates full" at its exclusive-use gates.

An airline hub-and-spoke operation presents a special case. Airports with hub-and-spoke operations experience several peaks of demand each day.[1]

OPERATING CHARACTERISTICS

During a daily 1- or 2-hr peak period, capacity of the gates (i.e., the number of flights that can be accommodated) is simply the number of gates or other aircraft parking positions in the complex. If the average gate service time is much shorter than the period of interest, for example because of a high percentage of commuter or through flights, then capacity may be somewhat higher.

As gate utilization increases, the risk of delay due to problems with operations increases. Frequent occurrence of such delays may indicate that the capacity of the gate system is being approached. Longer time gaps between departing and arriving flights at aircraft parking positions and gates generally imply greater flexibility to accommodate disruptions and variations in flight operations, and thus may represent higher service levels.

Generally, data are not recorded for gate area aircraft delay except when caused by airside problems. Useful definitions of service levels for aircraft parking positions and gates require such data.

The analyst must be explicit about the type of aircraft parking positions at an airport, because hardstands and remote parking positions may be included. Variation in how parking positions are counted and reported at different airports combined with the effects of diverse airline operating practices and airport lease arrangements account for the wide range in historic data on gate utilization. At Denver's Stapleton Airport, for example, average daily utilization at loading bridge-equipped gates currently varies from 1.5 to 12.0 flight turnarounds per gate per day. Similar statistics from the three major airports in the New York metropolitan region show a range from 2.5 to 17.6 flight turnarounds per gate per day.[2]

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

Relatively simple techniques, including a graphic technique published by the FAA *(4)*, are often used to estimate gate capacity on the basis of average achievable number of operations per hour given the percentage of gates able to accommodate a given type of aircraft, the fraction of the daily flight

schedule allotted to each aircraft type, and the average service time for each aircraft type. Airline use restrictions can be incorporated into such procedures by specifying different types of aircraft or by analyzing separately each airline's group of gates. These techniques do not take into account possible delays to aircraft operations if flights are too tightly scheduled and a disruption occurs.

A more sophisticated approach to assessing capacity involves examination of the ramp chart for a period such as the peak-month average day. When specific gates are not occupied, there may be time slots available to accommodate additional aircraft, depending on the gate use strategy at the airport. These slots must be at least long enough to equal the average service time of the type of aircraft being considered and must be available at the scheduled arrival and departure times of the aircraft. Computerized models have been developed (see Appendix B) to perform these slot calculations for the typical operating day. Adequate calculations can be made by hand for relatively small numbers of gates.

EXAMPLE OF ASSESSMENT PROCESS[3]

Suppose that a unit terminal at an airport has nine gates. Airport management would like to determine whether current flight schedules will permit additional service to be accommodated at these gates.

Describe Component

Each gate is equipped with a passenger loading bridge. Geometry of the apron area allows accommodation of only narrowbody aircraft. Current lease arrangements grant exclusive use of each gate to the lease holder. Six airlines hold leases on one to three gates each. Several other airlines use gates under subleases, operating one to two flights per day.

Describe Demand and Operating Factors

A ramp chart is drawn to show the current daily demand at the gate complex (Figure 6-2), which consists of 120 flight operations (e.g., 60 flights).[4] Several airlines use this airport as an overnight layover, leaving late-arriving aircraft parked for early-morning departure. Passengers are primarily vacation and leisure travelers during the airport's peak-month average day.

This ramp chart shows that aircraft service times vary substantially, from 30 min to more than 75 min, during the period when the airport is active (6:00

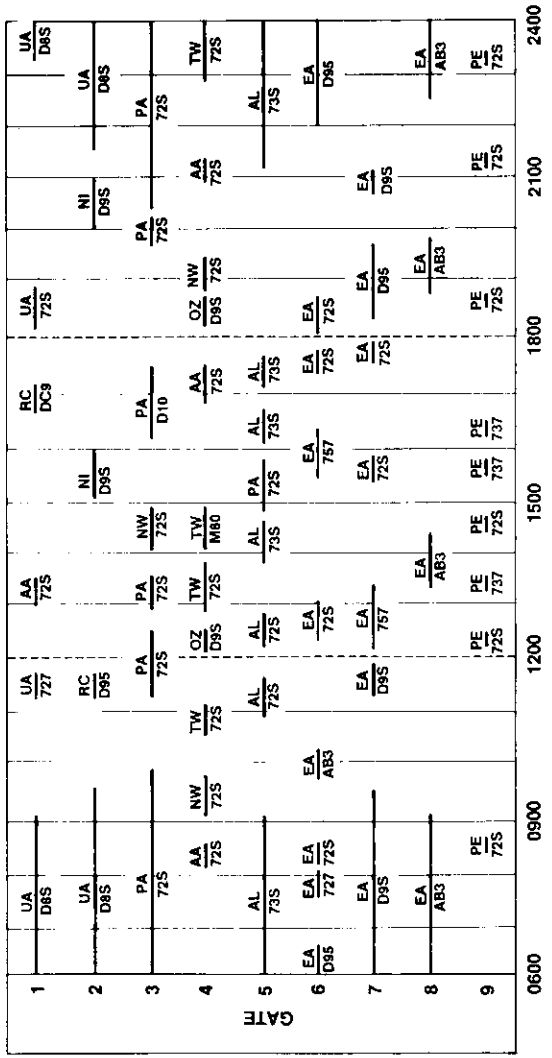

FIGURE 6-2 Ramp chart for example airport [adapted from McKelvey (5)].

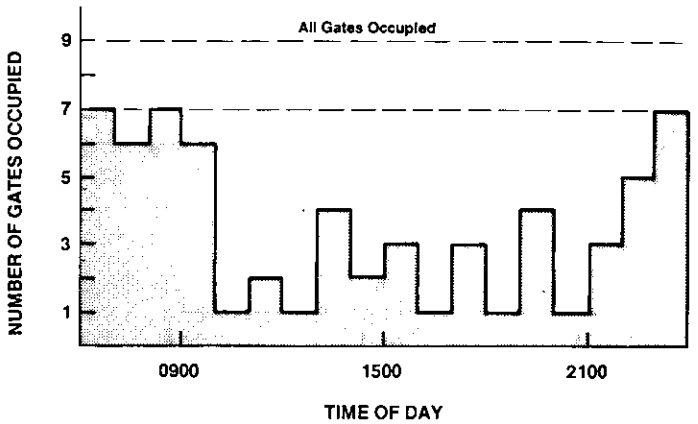

FIGURE 6-3 Aircraft on ground during average day.

a.m. to 11:00 p.m.). If overnight layovers are counted as 75 min of active gate use, the average turnaround time for 60 flights in a 24-hr period is slightly more than 30 min and the median time is approximately 45 min. Individual gates are empty for extended periods during the day, and at no time are all gates occupied (Figure 6-3).

Estimate Service Levels and Service Volumes

An indicator of current service level is given by the observation that during the active 17 hr of an operating day, the current ramp chart contains in principle 23 to 34 slots of 30 to 45 min each. A simple measure of gate utilization is the ratio of these slots to slots available:

$$\text{Utilization} = \text{flights}/[(\text{gates}) \times (\text{slots/day})]$$
$$= 60/[(9) \times (23\text{–}34)] = 0.20\text{–}0.30$$

This analysis suggests that additional capacity may be realized above the 60 flights per day now served if some of these slots could be filled with new flights. However, the formula does not allow for time required between departure of one flight and arrival of the next at a single gate position nor for inevitable day-to-day variations in flight operations. Attempts to achieve service volumes of 200 to 300 flights per day, based on estimated 100 percent utilization of the nine-gate complex, would unquestionably result in serious declines in service level. However, this simple method provides a useful initial indication that an increase in service volume may be achievable.

A somewhat more realistic analysis of gate utilization may be made by constructing a graph like that in Figure 6-3 from the ramp chart, which shows how many gates are available at any hour throughout the day. The ratio of the area under the plot of gate occupancy to the total area under the line of maximum gate occupancy is an indicator of gate utilization, and is computed as follows:

$$\text{Utilization} = \text{total aircraft at gates}/[(\text{gates}) \times (\text{hours})]$$
$$= 61/(9 \times 17) = 0.39$$

Using this measure, the airport operator might estimate that with 100 percent utilization a total schedule of about 150 flights per day would be achievable, although such a schedule would allow little flexibility for accommodating flight delays due to weather, air traffic, or ground service conditions. Also, the analysis fails to recognize that different types of flights and aircraft may have different gate service time requirements.

A still more exact estimate of gate capacity could be made by direct inspection of the ramp chart to identify open periods adequate to accommodate new flights. For example, if that duration is 60 min, approximately 72 such slots are available. If the required duration is 75 min, the number of slots declines to 46. At 90 min duration, the number is 34. Total flights at the nine-gate complex might in principle be increased to 94, 106, or 132 flights per day, depending on the time allotted for each slot. However, these increasing service volumes reflect a probable decline in service level indicated by the reduced time between scheduled flight operations. Selection of a realistic slot time duration depends on characteristics of expected flights, such as whether they are through flights or terminating ones, and the likely passenger loads.

To realize this capacity would require either that each airline schedule new flights to fully occupy its leased gates or that the gate use strategy be changed. Inspection of Figure 6-2 shows, for example, that the nine flights using Gate 9 could be served, with the exception of one arriving at approximately 8:30 a.m., at other gates. However, the airline operating these flights has exclusive use of Gate 9, which limits the current service volume to 120 flight operations. Fewer gates would be required to serve current demand if all gates were operated under a common use strategy and thus a considerably greater number of flights might then be served by the nine-gate complex.

RESEARCH NEEDS

Few data are now collected on delays due to landside problems such as gate access and holds. There is a pressing need to fill this gap in the comprehensive

statistical data base on air carrier delay and airport system operating capacity maintained by the FAA. Data on airline gate holds, delayed gate access for arriving flights, and similar measures of landside-based delay should be collected on a routine basis in a form compatible with data on airside delay statistics. Such data, reviewed within a context of other sources of delay, would be a basis for developing operationally justified service-level targets.

NOTES

1. Peaking in this case depends on airline scheduling as well as on underlying passenger demand for travel.
2. These daily statistics are taken from monthly reports by airport operators. Statistical analysis of annual operations at 153 U.S. airports indicates that at airports with 10 or more gates, daily service volumes as high as 18 flights per gate may be sustainable, but only under ideal conditions of aircraft mix, flight routes, airline operating practices, and weather conditions.
3. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).
4. Arrival and departure are considered separate operations. Each flight serving an airport thus results in two flight operations.

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7
Passenger Waiting Area

Passengers waiting in areas[1] serving aircraft gates and terminal lobbies may be subjected to crowding and congestion if facilities are inadequate. Availability of seating, general quality of the surroundings, and length of time the passenger waits have a substantial influence on perceived service levels in these areas.

DESCRIPTION

The number of passengers waiting for flight departures and arrivals depends primarily on the number of aircraft served by the waiting area, aircraft seating capacity, aircraft passenger load factors, degree to which passengers are accompanied by family or friends, passenger arrival time at the airport, and the length of time between commencement of boarding of a flight and its departure. Interdependence among components may have a substantial impact on number of passengers waiting in various areas of the terminal. For example, delays at a passenger security screening device may delay passengers' arrival at waiting areas, and thereby reduce the number waiting to board. Variations in aircraft departure times may increase the number of passengers waiting. For example, almost half of the departing passengers at New York City's John F. Kennedy International arrive two or more hours in advance of their scheduled departure times (Port Authority of New York and New Jersey, 1982 survey). Such behavior, related at least in part to the predominantly long-haul flight schedule at this airport, substantially increases the number of

passengers waiting in the terminal. Final steps in processing enplaning passengers, including seat assignment and ticketing, may impose delays and generally increase the length of time during which passengers occupy waiting areas as well as the number of people waiting.

Airlines normally seek to avoid crowding in their exclusive-use areas. However, during the 15 to 20 min before departure when about 70 to 90 percent of the passengers are in the vicinity of the gate, crowding is sometimes unavoidable. Design of a common waiting area for several gates is used at some airports to avoid severe crowding.

Demand and operating factors influencing service level and capacity in waiting areas are given in Table 7-1. Service levels and service volumes over

TABLE 7-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF PASSENGER WAITING AREAS

Factor	Description
Waiting and circulation area (lounge and accessible corridor)	Space available for people to move around and wait for departing flights; depends on terminal configuration, for example, waiting areas may be shared by passengers on several departing flights or restricted to single gate
Seating and waiting-area geometry	Seated people may occupy more space but are accommodated at higher service levels
Flight schedule, aircraft type, passenger load, and gate utilization	Larger aircraft typically mean higher passenger loads; areas used jointly to serve simultaneous departures
Boarding method	Availability and type of jetways, stairs, and doors from terminal to aircraft affect rates at which passengers board as well as airline passenger handling procedures
Passenger behavioral characteristics and airline service characteristics	How soon before scheduled departure people arrive at gate areas, amount of carry-on baggage, knowledge of system, and percentage of special needs passengers (families with small children, elderly, handicapped, first class and business travelers); airline passenger service policy, seat assignment and boarding pass practices

the short run—typically a period of one-half to three-quarters of an hour—are determined primarily by comparing areas available to passengers, the number of passengers waiting and the amount of baggage they have with them, and targets for available space per person.

DEMAND PATTERNS

The number of passengers waiting is determined by flight schedules and passenger behavior, including the length of time it takes for passengers to pass through the other components of the landside. The number of waiting passengers in an area generally is greater when passengers arrive at the airport early for their flights and decreases when more time is required for check-in or transfer. Waiting areas such as gate lounges serve originating and transfer passengers, whereas terminal lobbies accommodate primarily originating passengers and their nontraveling companions. When weather or air traffic conditions disrupt flight operations schedules, corridors and airline passenger service counters may become important passenger waiting areas and help to maintain higher service levels throughout the terminal as the number of waiting passengers increases.

Demand is frequently expressed as the percentage of departing passengers arriving at the waiting area in discrete intervals of time before scheduled flight departure. Rules of thumb have been proposed to generalize this relationship, but direct observation of conditions at a particular airport remains the only reliable way of describing demand patterns.

Peak demand levels are likely to occur during periods when all gates in a terminal concourse are occupied by flights with closely scheduled departure times. Airline hub-and-spoke operations, with their limited scheduling windows, are likely to exhibit sharp peaking of waiting-area occupancy levels.

OPERATING CHARACTERISTICS

Effective design is the primary means for assuring adequate service levels in waiting areas. Some of the more frequently used design space standards for gate lounges and other terminal waiting areas are given in Table 7-2 *(1–5)*. These standards appear to be generally upheld in current practice, except perhaps at those airports where introduction of larger aircraft or a new airline hub-and-spoke operation has produced larger passenger loads per gate than was anticipated in design. Service-level targets for lounges may differ among airlines and among airports but are typically based on market conditions. For example, the management of New York City's La Guardia Airport tries to maintain 10 ft^2 per person in gate lounges, whereas planning for the expansion of John F. Kennedy International with its different passenger mix is based on a target of 15 ft^2 per plan-year passenger (design memorandum, Port Authority of New York and New Jersey, 1985–1986).

TABLE 7-2 TYPICAL SPACE STANDARDS USED IN PLANNING AND DESIGN

Design Situation	Space Standard (ft^2/person)
IATA design standard for departure lounges *(1)*	8.5 per aircraft seat
IATA suggested breakdown level of service in holdrooms *(2)*	> 6.5 for more than 15 min
IATA suggested breakdown level of service in waiting and circulation areas *(2)*	> 10.8 for more than 15 min
Unofficial FAA minimum-space guidelines for departure lounge design *(3)*	6.7–10.0 per aircraft seat; 15 per seated waiting passenger
Architectural reference standard for adequate waiting and circulation space with baggage *(4)*	13
Design loading of urban transit vehicles *(5)*	3–4

NOTE: IATA = International Air Transport Association.

Transporter vehicles used in some airports to connect the terminal to remote apron parking areas are a special case. The transporter vehicle serves as an extension of the gate lounge during the time between commencement of boarding and transporter departure. Standards within the transporter vehicle are generally lower than those for gate lounges and may approximate those used in design of urban transit vehicles (Table 7-2). Capacity is generally determined by manufacturers' standards.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

In analyzing the capacity of passenger waiting areas, service levels are usually indicated by the ratio of the number of people in the area and the size of that area. Targets for this ratio may vary with the time passengers wait for boarding, but in many cases, only a space standard is stated. Airlines may also employ standards for the number of seats that should be available for given numbers of passengers.

In most applications, estimation of passenger demand over time is necessary. Observation and sample passenger counts are often used to make these estimates. Mathematical queueing and simulation models to predict the arrival of enplaning passengers at waiting areas before scheduled departure may also be used (see Appendix B). Simulations for the terminal building as a whole may be used to develop curves of the percentage of a flight's passenger load likely to be in the gate lounges of that terminal during discrete time intervals before scheduled flight departure. Often these curves indicate simply the number of people expected to be in the waiting area versus the time before

departure. These curves may then be used to determine whether introduction of new aircraft or scheduled flights would create overload conditions. Such models and field observations may be used to develop standard distributions of passenger arrivals over time for particular types of flights at a particular airport. These standard distributions may then be used to approximate expected conditions if new services are introduced or new facilities are being planned.

EXAMPLE OF ASSESSMENT PROCESS[2]

Assume that there is a departure lounge serving a single gate. The lounge is fully enclosed except for the entry where airline personnel check tickets and assign seats and is thus relatively isolated from other waiting areas. Figure 7-1 shows such a departure lounge. Seating in the lounge has been arranged to permit free circulation of passengers with carry-on baggage in the area near the aircraft loading bridge entry. Additional seating might be provided at the airline's discretion.

Describe Component

This gate is currently leased by a major commercial service carrier that normally schedules Boeing 727 aircraft for this gate but may soon schedule the Boeing 767 also.

The departure lounge is large, with a gross floor area of approximately 2,900 ft². Net space for passengers, deducting the corridor for deplaning passengers and the check-in counter area, is approximately 2,600 ft². There is currently seating for 96.

Describe Demand and Operating Factors

Experience at the airport has shown that 80 percent of the passengers on a flight are likely to be in the gate lounge 20 min before scheduled departure. When the airline begins boarding, normally 15 min before scheduled departure, this fraction may be 87 percent.

During the busy month of August, this airline's flights have an average load factor of 85 percent, and during the busiest parts of the day, flights are usually

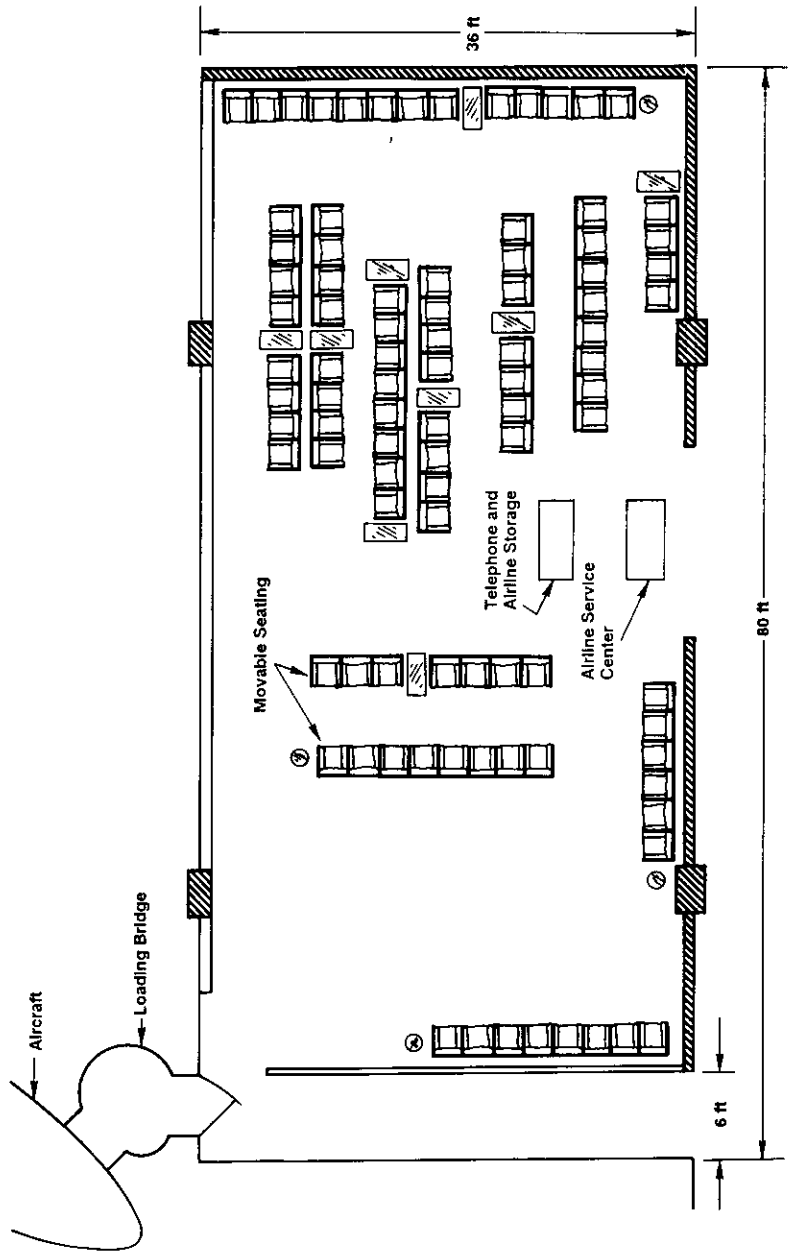

FIGURE 7-1 Example departure lounge.

full and there are standby passengers waiting. For flights served by Boeing 727 aircraft, which have a seating capacity of approximately 130 to 160 passengers, there are typically 110 to 140 passengers in the lounge just before boarding. When boarding begins, the number of passengers waiting in the lounge area begins to decline.

One agent is assigned for boarding, able to pull tickets and check boarding passes at a rate of approximately 10 passengers per minute. Flight schedules and aircraft service procedures keep this gate busy, with approximately one aircraft arriving and departing every hour.

Estimate Service Levels and Service Volumes

Because only one flight uses the gate per hour, performance of the gate agent determines maximum throughput. The agent can board 10 passengers per minute or a total of 150 passengers in the 15 min used for boarding. That is,

Throughput = boarding rate × boarding time
= [(10 passengers per minute per agent) × (1 agent)] × (15 min)
= 150 passengers per flight

However, passenger demand reflected by aircraft loads is not that high.

The airline operates a premium service and attempts to ensure that its passengers are comfortable. The company would like to maintain a target service level of at least 15 ft² per passenger when the departure lounge is most heavily occupied, which is usually immediately before flight boarding begins, and would like most passengers to have a seat available in the lounge. The airline is concerned that starting service with new aircraft will cause what this airline believes to be excessive crowding, that is, less than 15 ft² per person. This is an unacceptably low service level for this airline in this market, although it is a relatively high target when compared with the 8–10 ft² per passenger used in many planning and design studies.

The service-level target establishes the maximum service volume of the lounge:

Maximum service volume = lounge area/space standard
= 2,600 ft²/(15 ft²/passenger) = 173

Given the pattern of passenger arrivals at the lounge, this maximum service volume would be 87 percent of the flight's passenger load. The gate lounge

can then accommodate an aircraft with as many as 199 passengers and still meet the service-level target.

The Boeing 727 aircraft is clearly in an acceptable range, with typical load levels of 110 to 140 passengers. With 96 seats in the lounge, approximately half of the capacity load can be seated and over two-thirds of the typical B-727 passenger load. In the absence of a specific seating standard, this figure would be considered acceptable. If Boeing 767 aircraft are introduced, with 210 to 230 seats per aircraft, the airline's service-level target may be violated if load factors and passenger behavior do not change.

RESEARCH NEEDS

Architectural and planning standards for waiting areas appear to be adequate for decision making. Although questions may arise in particular cases of facility design, general research on space standards is not a high-priority need.

Similarly, airlines operating gates on an exclusive-use basis will set their own standards for boarding times. However, airports considering joint-use operations may benefit from having better data on reasonable lengths of time to board for different types of aircraft to serve as a basis for setting schedules.

NOTES

1. Waiting areas adjacent to gates, which may be typically termed gate lounges, departure lounges, or holdrooms, are the principal focus of this discussion. However, the design of some airports includes waiting areas outside the immediate vicinity of the gate lounge or holdroom for a particular gate but close enough to be used by passengers for that gate. Therefore, the more general term "waiting area" is used here to cover all available waiting space.
2. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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8
Passenger Security Screening

All originating passengers must pass through a security screening. In addition, interline transfer passengers at some airports may be required to clear a security screening on their way to a connecting flight. These areas are often points of queueing and delay for passengers.

DESCRIPTION

Passenger security screening occurs in concourse corridors at entrances to terminal gate areas or at the entry to gate lounges. Equipment configuration and staffing are the primary factors influencing capacity. Corridor width often controls screening capacity, determining the number of inspection channels that can be set up.

Each channel consists of a metal-detecting device (magnetometer) through which a passenger walks and one or sometimes two x-ray devices for inspection of carry-on luggage. Inspectors may undertake additional screening at their discretion, including hand searching of carry-on items and close screening (using a hand-held magnetometer) of individual passengers.

Security is often supervised by the airport operator. Sometimes airlines, in cooperation with the airport operator, hire security personnel themselves and establish their own procedures to supplement or replace those of the airport operator. Heightened concern over possible terrorist threats has led a number of airlines, especially overseas carriers, to augment their security screening procedures.

Demand and operating factors influencing service level and capacity for passenger security screening are given in Table 8-1. Because of the steady flow of passengers served at most security screening areas and because the

TABLE 8-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF PASSENGER SECURITY SCREENING AREAS

Factor	Description
Number of channels, space, and personnel	Influences number of passengers processed per unit time (magnetometer and x-ray considered separately)
Type, equipment sensitivity, and airport/airline/agent policy and practice	Determines average service time per passenger and likelihood of close inspection
Passenger characteristics	Amount of hand luggage, mobility, and patterns of arrival influence average service time as well as number of passengers
Building layout and passenger circulation patterns	Interference among pedestrian flows can influence flow rates and create congestion
Flight schedule and load	Basic determinant of number and direction of people on concourse

security screening is among the last of several possible barriers facing departing passengers, short-term capacity of this component is the primary concern—queues typically build and clear over short periods. Assessment of delays related to security screening is usually made with respect to a peak 1-hr period, but attention should also be given to the shorter time over which service quality can decline.

DEMAND PATTERNS

The timing of passengers' arrival at the gate for flight departure determines the basic demand on security screening facilities. Patterns of this timing have been documented at specific airports. When such data are not available, arrival patterns can be estimated from passenger arrival times at the airport if allowance is made for the several parallel paths by which passengers reach the security screening area. In addition to passenger demand, other people accompanying passengers to the gate area—nontravelers—typically must pass through security screening as well.

Processing rates at the security screening area are affected by the number and size of pieces of hand luggage carried on. Holiday travelers, tourists, and business travelers seeking to avoid checking baggage may have a larger number of parcels to be inspected. High percentages of passengers in wheelchairs or children in strollers may also lead to slower processing.

To reduce the total number using the security screening area, many airports have posted signs discouraging nontravelers from entering the secure area. This restriction is enforced in some airports by requiring passengers to show their tickets or boarding passes before entering the security screening area.

OPERATING CHARACTERISTICS

The sensitivity of magnetometers can be varied to pick up smaller amounts of metal on the passenger's person. Less sensitive settings will tend to decrease average service time by reducing the frequency of intensive inspections.

When passengers arrive at rates exceeding the service rate of the security screening area, queues form. The delays associated with waiting in this queue are the principal basis for judging the service level of the passenger security screening area. Observed processing times for security screening are presented for several airports in Table 8-2.

TABLE 8-2 TYPICAL PROCESSING TIMES FOR SECURITY SCREENING *(1, 2)*

Airport	Average Processing Time (min/passenger)
Miami *(1)*	0.47–0.51
Denver *(1)*	0.18–0.56
La Guardia *(1)*	0.15–0.77
La Guardia (five concourses)[a]	0.62–0.90
Kennedy (eight unit terminals)[a]	0.07–0.16
Hand-checked baggage *(2)*	0.50–1.00
Automated check *(2)*	0.50–0.67

[a]Survey by Port Authority of New York and New Jersey.

In some situations space for passengers to queue may be limited, and crowding may become another important element of service level. Data on passenger delays and queue lengths for security screening are not generally available. A British survey of passenger attitudes found that passengers were willing to tolerate delays of 6.5 to 10.5 min per passenger before they judged the level of service to be bad *(3)*. However, U.S. practice suggests that such delays are encountered only rarely. A delay of 5 min, for example, at a facility with service and demand characteristics producing an average service time of 0.50 min per passenger would indicate an average queue length of 9 to 10 passengers. At typical peak-period passenger volumes, small differences between service and arrival rates can rapidly cause large queues to build. Persistence of such queues during a peak hour is often evidence of a capacity problem at the security screening area.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

Among the various components of the airport landside, security screening most closely fits the assumptions of a simple queueing model. The average time required for clearance of a passenger, the variability of that time, and the rate of passenger arrival at the security screening area are key variables for capacity assessment.

EXAMPLE OF ASSESSMENT PROCESS[1]

Assume that there is a single corridor leading to a concourse of 10 gates, all used by a single airline. After ticketing, departing passengers must pass through a security screening at the beginning of this corridor (Figure 8-1).

Describe Component

The equipment consists of one magnetometer and one x-ray machine with belt drive manned by a single inspector. Two other inspectors are generally on duty to relieve the x-ray operator and to conduct hand searches of luggage and close inspection of passengers who set off the magnetometer alarm.

The corridor is intersected by a circulation corridor through which passengers from other airlines pass in their trip from the terminal lobby to gates. This cross flow may become congested when traffic in both directions is heavy or when a long queue builds at the security screening area. Although this problem has occurred with fair regularity, no detailed data have been collected on passenger flows through the security screening.

Describe Demand and Operating Factors

The passengers using this security screening area are primarily business travelers taking 1- to 3-day trips. They generally have carry-on luggage, seldom check bags, and tend to arrive at the airport with as little time before their scheduled flight departure as they believe prudent. The airline has observed that 40 percent of their passengers at this airport typically

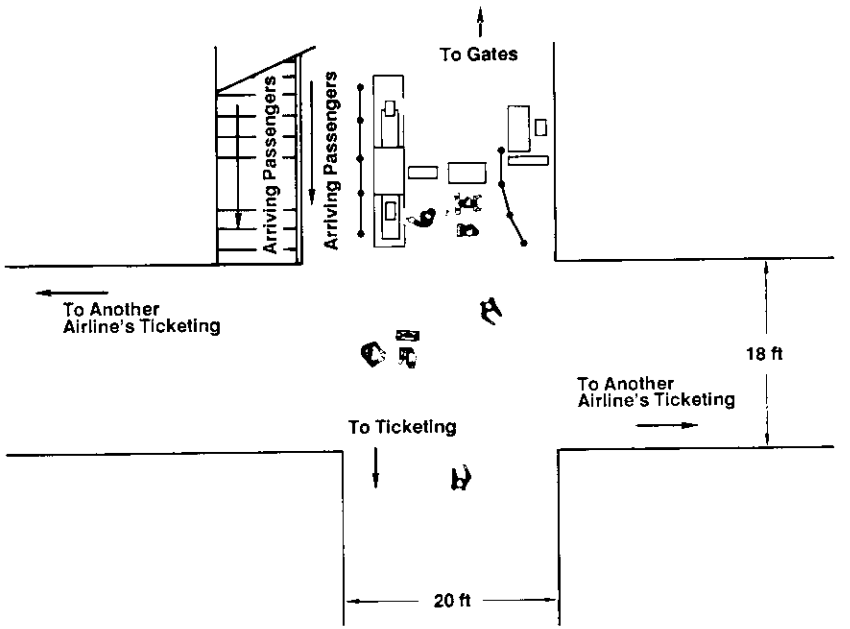

FIGURE 8-1 Example of passenger security screening.

arrive within 1/2 hr of their scheduled flight. The fraction increases to 60 percent 20 min before flight time and to 95 percent 10 min before flight time.

The airline's flight schedule is arranged to serve these travelers, with peak numbers of departures in the early morning, at midday, and in late afternoon. Each of these peaks has a 20-min period when six flights are scheduled to depart, each flight served by aircraft with seating capacity of approximately 110 passengers. Over the course of each peak hour, there are 10 such flights. The airline's load factor is approximately 78 percent, except during the hectic Christmas and Thanksgiving seasons, when it is higher, and during the relatively quiet August vacation period.

The airline's observations of passengers' arrival characteristics indicate that 35 percent arrive in the first 10 min of the 20-min period before flight time. Under the worst case, with all six peak-period flights scheduled for the same departure time, the peak passenger arrival rate may be estimated as follows:

$$\begin{aligned}\text{Peak arrival rate} &= (\text{no. of flights} \times \text{aircraft capacity}) \times (\text{load factor}) \times (\text{percent arriving in peak time}) \\ &= (6 \times 110) \times (0.78) \times (0.35) \\ &= 180 \text{ passengers during the peak 10 min}\end{aligned}$$

The security screening system achieves a normal average inspection rate of approximately 15 passengers per minute. During peak periods passenger behavior and inspection procedures may cause the rate to increase to 18 passengers per minute.

Estimate Service Level and Service Volumes

On the basis of the inspection rates achieved, the security screening normal throughput is estimated as follows:

Normal throughput = (normal inspection rate) × (time)
= (15 passengers/min) × (20-min peak)
= 300 passengers in peak 20 min
= (15) × (60) = 900 passengers per hour

During peak times the maximum throughput is

Peak maximum throughput = (peak inspection rate) × (time)
= (18 passengers/min) × (20-min peak)
= 360 passengers in peak 20 min
= (18) × (60) = 1,080 passengers per hour

The capacity of the security screening would then be in the range of 900 to 1,080 passengers per hour. The actual hourly service volumes are much lower:

Demand service volume = (flights) × (seats) × (load factor)
= (10) × (110) × (0.78)
= 858 passengers

The security screening appears to be adequate on this hourly basis.

However, the peak arrival rate is estimated to be 180 passengers during a 10-min period, or about 18 passengers per minute. Because this rate results in a higher than normal throughput, this is a worst-case situation in which queueing may occur until the processing rate catches up with passenger arrivals. The total estimated length of the queue is the difference between the number of arrivals—180 passengers—and the number served—at 15 passengers per minute, 150 during this peak 10 min—or approximately 30 passengers.

As a service-level target, the airline has suggested that passengers never encounter delays of more than 3 min at the security screening, although management recognizes that occasional lapses may occur during holiday seasons. The last person entering the queue would require approximately 2 min to pass through security (at a rate of 15 passengers per minute for those ahead of him to clear the facility), which is well within the airline's standards.

RESEARCH NEEDS

Substantial research efforts are being directed toward developing new devices for screening both passengers and baggage. To the extent that new devices are introduced and influence average service times, data on these new times will be needed to ensure that security screening does not become a constraint on landside capacity.

NOTE

1. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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1. P. Mandle, F. LaMagna, and E. Whitlock. *Collection of Calibration and Validation Data for an Airport Landside Dynamic Simulation Model.* Report TSC-FAA-80-3. Federal Aviation Administration, U.S. Department of Transportation, April 1980.
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9
Terminal Circulation

The terminal circulation component is used by all air passengers, but the focus of this chapter is primarily on the beginning or the end of their trip at the airport of interest. Conditions facing passengers transferring between connecting flights are addressed in Chapter 16.

DESCRIPTION

Generally speaking, the total time it takes for a passenger to move through the airport's landside is the sum of the time waiting for service and being served at each of the functional components used along the way, such as check-in or baggage claim, plus the time required to travel between components. If only the travel time is added, the sum represents an estimate of the time it takes to travel through the landside without stopping. A business traveler with all tickets and boarding passes in hand and with no luggage to check or retrieve might allow just this much time plus time for brief delays at the security screening, at the gate awaiting departure, and at ground transportation for the terminal portion of his trip. Except at airports where individual airlines exercise complete control over unit terminals, virtually all aspects of this terminal circulation component are the responsibility of the airport operator.

The principal demand and operating factors influencing service level and capacity for the terminal circulation component are given in Table 9-1. These same factors may be cited for their influence on general circulation. For elevators and people movers, details may also be required on the dimensions and operating characteristics of the specific mechanical system.

TABLE 9-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF TERMINAL CIRCULATION

Factor	Description
Terminal configuration	Space available for people to move freely without conflict of flows; availability of alternative paths; placement of seating, commercial activity, stairs, escalators
Passenger characteristics	Amount of hand luggage, mobility, and rate of arrival before scheduled departure influence demand loads and service time
Flight schedule and load	Basic determinant of number and direction of people on concourse

NOTE: These same factors affect circulation on elevators and people movers; specific mechanical systems, however, may differ.

DEMAND PATTERNS

Passenger demand within this component is determined primarily by patterns of passenger arrival at the airport before scheduled flight departures, by the paths passengers take going between gates and the terminal curb, and by speeds at which both arriving and departing passengers make this trip. The rate at which passengers move through the landside depends on such characteristics as age, purpose for the travel, and time available before the flight or following the arrival; on the degree of crowding encountered along the way; and on the geometry of the path traveled. Typical free-flow distributions of walking speeds in areas similar to an airport terminal (Figure 9-1) show considerable variation. As the average circulation space per person falls below approximately 10 to 15 ft^2, walking speed may begin to decrease substantially below these free-flow levels (*1*, p. 13-7).

OPERATING CHARACTERISTICS

Although terminal building design determines what routes may be available to passengers, airport operators and airlines personnel can use partitions and signs to direct passenger traffic and improve overall terminal circulation in an attempt to optimize the path a passenger must take through the terminal building. Escalators and elevators may become bottlenecks but generally improve service levels. Reduction of the degree of physical obstruction and likelihood of intersection of pedestrian paths going in different directions tends to improve pedestrian travel speeds and reduce congestion.

Passengers normally do not take the shortest route through the terminal. In a study of Vancouver International Airport, for example, Transport Canada

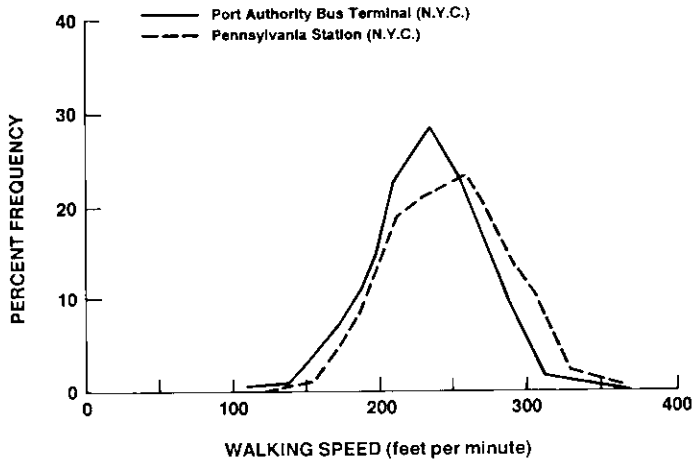

FIGURE 9-1 Typical free-flow pedestrian walking speeds *(1)*.

found that actual walking distances of travelers were 1.3 to 2.1 times longer than the ideal shortest-path route. In two sections of the terminal, the ratio exceeded a factor of 5 *(2)*. Concessions, rest rooms, and pay telephones located along corridors typically create some congestion and slow general travel speeds as well as increase the path lengths of the passengers who use these facilities.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

In general, the terminal circulation component may be considered a pedestrian circulation problem and analyzed by using procedures and standards such as those suggested in TRB's *Highway Capacity Manual (3)*. The length of the passenger's pathway, the passenger's walking speed, number of level changes, and the degree of interference the passenger encounters along the way are key variables in the assessment.

The time spent traveling between curb and gate is the principal measure of service level and a determinant of capacity. Number of level changes and how complicated the pathway appears to the passenger may also affect service levels. Very little generally comparable data have been collected for describing circulation service levels at typical airports.

Service-level definitions presented in the *Highway Capacity Manual* may be useful at airports and should be considered when circulation problems

develop. Procedures suggested in that report may be useful in assessing the capacity of specific terminal design configurations.

EXAMPLE OF ASSESSMENT PROCESS[1]

Consider the situation described in Chapter 8 for passenger security screening. Passenger flow (i.e., pedestrians) in a circulation corridor crosses flow going to and from the security screening for a concourse of 10 gates. The airport operator wishes to determine what the maximum tolerable queue length at the security screening is such that pedestrian cross traffic is not seriously impeded.

Describe Component

The circulation corridor is 18 ft wide, unobstructed by columns or furniture (see Figure 8-1). It is intersected by another corridor 20 ft wide leading to the security screening devices. Pedestrian flow in the circulation corridor is typically 75 to 85 percent in one direction, with that direction depending on time of day.

Describe Demand and Operating Factors

Airport planning staff is assigned to observe the pedestrian flows during busy periods for one week. When there are no queueing problems at the security screening, volumes in the circulation corridor are in the range of 110 to 130 pedestrians per minute in the peak direction and 35 to 45 pedestrians per minute in the opposing direction.

Walking speeds were not recorded, and therefore must be assumed.

Estimate Service Levels and Service Volumes

The airport operator decides that the conditions described in the *Highway Capacity Manual* as level-of-service D are tolerable, but only for short intervals—15 to 25 min at a time, two to three times a day. As described in the manual, level-of-service D represents restricted pedestrian walking speeds, and the probability of conflict with pedestrians moving across the flow or in

the opposite direction is high. Although flow remains "reasonably fluid," considerable friction and interaction are likely *(3)*.

The manual suggests that level-of-service D is achievable with pedestrian flows of up to 15 pedestrians per minute per linear foot of corridor cross section, and with average space as low as 15 ft² per person. Using these figures as targets, the following estimates of capacity may be made:

Corridor service volume ≤ (flow standard for level of service) × (corridor width)
≤ (15 ped/min/ft) × (18 ft)
≤ 270 ped/min for both directions

This volume is considerably higher than the total of 145 to 175 pedestrians per minute observed by staff.

Applying the space standard in the crossover area shared between the two corridors, the following estimate is made:

Maximum pedestrian density ≤ (area)/(density standard)
≤ (18 ft × 20 ft)/(15 ft²/ped)
≤ 360/15 = 24 pedestrians in the crossover area

Suppose an average pedestrian walking speed of 180 ft/min is assumed (see Figure 9-1). Each passenger would require approximately 6 sec (0.1 min) to cross the circulation corridor and enter the security screening channel. If passengers are being processed at the security screening at a peak average rate of 18 per minute (see Chapter 8), or 1 every 3.3 sec, there will be 1 to 2 such passengers in the crossover area at any one time. Similarly, passengers walking at the same average speed in the circulation corridor are in the crossover area for approximately 6.7 sec, implying that at flow rates of 145 to 175 pedestrians per minute, there will be 16 to 20 such pedestrians in the crossover area. The total number of pedestrians in the crossover area then is 17 to 22, still within the range likely to maintain the service level above level-of-service D. Some blockage of the circulation corridor can therefore occur without violating the service target.

The ratio of current observed pedestrian flows to achievable maximum flows for the target standards is 35 to 45 percent. This fraction of the 18-ft width of the circulation corridor represents the tolerable blockage by passengers queued at security, a queue of 6.3 to 8.1 ft. Such a queue would constrict the flow of people in the circulation corridor and increase density to the limit allowed by the target. If queueing passengers occupy 2.5 to 3 ft per person, the tolerable queue length is no more than three to four people.

RESEARCH NEEDS

Although research conducted to ensure that terminals are free of barriers to the handicapped has contributed to knowledge about special circulation needs, there is still relatively little information on walking speeds for various types of passengers in airports. Research on these speeds is needed to develop service-level standards that can be readily adopted by a range of airports. Further, the frequency with which airports experience circulation problems indicates that this component warrants greater attention than it is now receiving.

NOTE

1. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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1. J. Fruin. *Pedestrian Planning and Design.* Cited in *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
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10
Ticket Counter and Baggage Check

Operation of the ticket counter and baggage check component begins when the passenger enters a queue to obtain a ticket and check his baggage and ends when that passenger leaves the ticket counter area. Curbside baggage check is a part of this component. The focus of this chapter is on activities located primarily within the terminal building.

DESCRIPTION

Airlines normally rent ticket counter space from the airport operator and manage this space on an exclusive-use basis. This leased area may include office space for administration and baggage handling. Airline personnel staff the ticket counters and operate according to procedures and standards set by the individual airline. The principal demand and operating factors influencing service level and capacity for the ticket counter and baggage check component are given in Table 10-1.

In general, each airline establishes its own service standards for this component on the basis of company policy and local competition. Airlines may operate counter positions to segregate passengers by class of travel (e.g., first class, frequent traveler) and by service required (e.g., checking baggage only, purchasing tickets). Baggage handling facilities are at many airports the single largest airline component and may play a dominant role in facilities planning.

In some airports a single queue may feed a bank of check-in positions. Service rates and preexisting queues determine the waiting time encountered by passengers in a peak period. Long queues do not necessarily indicate that

TABLE 10-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF TICKET COUNTER AND BAGGAGE CHECK

Factor	Description
Number and type of position	Processing rates are function of position type (baggage check only, ticket purchase, frequent or first class traveler, etc.)
Airline procedures and staffing	Number of positions manned and processing times
Passenger characteristics	Number preticketed or with boarding pass, amount of luggage, and distribution of arrival before scheduled departure influence demand loads, fraction of passengers by-passing check-in
Space and configuration	Available waiting area for queues approaching agent positions; banked or separate queues; conflict with circulation patterns
Flight type, schedule, and load	Basic determinant of number of people arriving at ticket area
Airline lease agreement and airport management practices	Counter use policy, as formalized in lease agreements, similar to gate issues and options

the component has a capacity problem. The length of time required to go through the line and the amount of waiting room available for each person in the queue are generally the minimum criteria for judging service levels.

DEMAND PATTERNS

Passenger demand is determined primarily by scheduled flight departure times, types of aircraft, and load factors. Length of arrival time before a scheduled departure may be expected to vary by type of service offered and by size of airport. Some airports survey departing passengers to develop representative distributions of such arrival times; an example determined in 1985 by the Port Authority of New York and New Jersey is shown in Figure 10-1.

Surges of demand may occur within the peak period for the airport as a whole, particularly during arrivals of groups of passengers from airport buses or other high-occupancy ground transport vehicles. Average demand conditions over the course of a peak hour are generally an appropriate basis for making judgments about service and capacity. However, airline or ground access operations may create sharp variations in passenger demand, making it more appropriate at some airports to use shorter periods such as 15 to 30 min.

Increased use of advance ticketing and seat assignment has raised the fraction of passengers bypassing the ticket counter and baggage check component. At New York City's major airports, the fraction of passengers able to

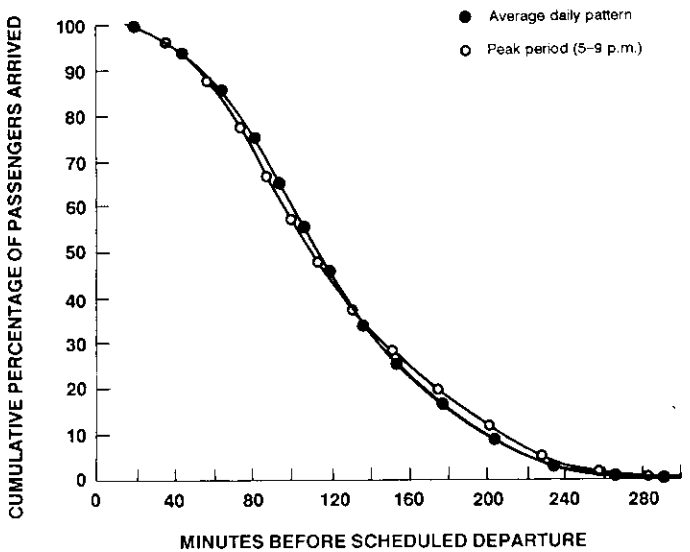

FIGURE 10-1 Observed departing-passenger arrival times at John F. Kennedy International.

avoid stopping at the ticket counter has been observed to vary from almost none on international flights, for which passports must be checked, to more than 40 percent on airlines serving primarily business travelers *(1)*.

OPERATING CHARACTERISTICS

Data from several U.S. large hub airports show that average processing or contact time per passenger at ticket counters varies widely. A sample of experience at several larger airports showed times in a range of 1.4 to 5.6 min (Table 10-2). Typical processing time at express check-in counters in this sample is 50 to 70 percent of that for full-service counters. Processing times at any particular airport will depend on airline staff experience, flight market, and passenger characteristics, as well as on airline operating policies. Surveys are typically required to determine these times.

Passenger processing times may vary substantially around the average. In Vancouver, Canada, for example, the average processing rate for a bank of ticket counters was observed to be 23 passengers per hour, or approximately 2.6 min per passenger. However, detailed observation showed that 60 percent of the passengers were served in less than 2.7 min each, and for 20 percent of the passengers more than 4 min was required *(3)*.

TABLE 10-2 TYPICAL PROCESSING TIMES OBSERVED AT TICKET COUNTER AND BAGGAGE CHECK *(1, 2)*

Airport	Typical Service Time (min)
Miami *(1)*	
Full service	1.9–5.6
Express	2.3
Denver *(1)*	
Full service	1.8–3.9
Express	1.5–2.7
La Guardia *(1)*	
Full service	2.8–5.5
Express	1.2–3.1
La Guardia (five concourses)[a]	1.4–2.6
Kennedy (eight unit terminals)[a]	1.4–4.0
Manual ticketing *(3)*	
With baggage	3.0–4.0
Without baggage	1.7–3.3
Baggage only *(3)*	0.5–0.8
Automated ticketing *(3)*	
With baggage	2.7–3.7
Without baggage	1.5–3.0

[a]Survey by Port Authority of New York and New Jersey.

TABLE 10-3 SPACE STANDARDS FOR TERMINAL CHECK-IN AREAS *(4, 5)*

Source	Space Standard (ft^2/person)
IATA level of service *(4)*	
Level A (excellent)	> 17.2
Level E (inadequate)	< 10.8 for > 15 min
System breakdown	< 8.6 for > 15 min
FAA implied guidelines *(5)*	
Multipurpose check-in	15–23
Baggage check only	12–18
Ticketing only	4.3–7.6

NOTE: IATA = International Air Transport Association.

Data are not generally available on actual crowding conditions in check-in areas of U.S. airports. Frequently applied architectural and planning space standards are summarized in Table 10-3. A guideline of 8 ft^2 per person, for example, allows approximately a 3-ft separation between passengers in a queue. Typical airport design standards call for a queueing space 15 ft deep in front of ticket counters *(5)* and specify different spacings between service

positions to allow for different functions. However, because airports differ with regard to geometry and services, there are many different passenger queueing patterns.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

Capacity of the ticket counter and baggage check component is judged by considering the average time required for processing passengers and by comparing number of passengers in the terminal lobby queueing area with the size of that area. Direct observation or simple queueing analysis is often used to estimate both the average wait time and the number of people waiting.

Observations in several large East Coast airports indicate that queue lengths of 8 to 10 persons may trigger the opening of additional counter positions, when available, by short-haul domestic service airlines. Queues for international departures are typically permitted to grow longer. Such queues represent delay and possibly crowding for the passenger.

A survey at Birmingham International Airport in England (Table 10-4) confirms that the length of wait time that passengers find tolerable varies substantially with the market being served. Passengers for scheduled European flights were satisfied with times of 7.5 min or less and found times of 14 min or greater "intolerable." Passengers for scheduled long-haul flights—mainly vacationers—were willing to tolerate wait times almost twice those of the short-haul market. Charter passengers were willing to tolerate waits in the range of 11 to 21 min *(4)*.

EXAMPLE OF ASSESSMENT PROCESS[1]

Assume that there is a single ticket counter, manned by one agent, as shown in Figure 10-2.

TABLE 10-4 VARIATION OF TOLERABLE WAIT TIME AT CHECK-IN FACILITIES FOR BIRMINGHAM INTERNATIONAL AIRPORT *(6)*

	Wait Time (min) by Passenger Rating	
Market Segment	Good to Tolerable	Good to Bad
Scheduled European	7.5	14
Scheduled long haul	15	25
Charter	11	21

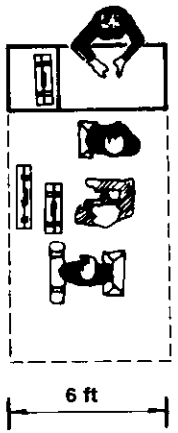

FIGURE 10-2 Example of ticket counter and baggage check.

Describe Component

The physical dimensions of the terminal are such that the counter position has a queue waiting area of 60 ft² and is equipped to handle baggage and full ticketing of passengers.

Describe Demand and Operating Factors

Suppose that passengers arrive at the counter area unaccompanied, so only passengers with few pieces of luggage are waiting in the queue.

Passengers arrive at the counter during a peak hour according to the pattern shown in Figure 10-3. During the first 15 min, six passengers arrive at the counter at fairly uniform intervals of 2.5 min apart. The arrival rate then increases, so that by the end of the first half-hour, 10 more people have arrived, a total of 16. All peak-hour passengers, a total of 20, have arrived by the end of 55 min. No passenger arrivals are expected during the final 5 min of the peak hour.

An experienced agent staffs the counter. In spite of the diverse demands placed on the agent, an average service time of approximately 3 min per passenger is maintained during the peak period.

Estimate Service Levels and Service Volumes

Maximum average throughput of the counter is estimated as follows:

Throughput = (peak-period time)/(expected service time)
= (60 min)/(3 min/passenger) = 20 passengers/hr

This estimate suggests that all passengers can be served during the hour. However, during the first 15 min of the peak period, six passengers arrive at a steady average rate. Only five are served and leave the counter, so there is, on average, someone at the counter throughout the period. Thus queues begin to grow as passengers arrive more quickly during the next 15 min.

At the end of the first 30 min, when 16 people have arrived and only 10 have been served, the queue reaches its maximum length of 6 in the queue area, and the waiting time increases to 18 min for the sixth passenger (five passengers

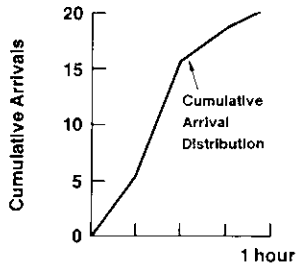

FIGURE 10-3 Distribution of passenger arrivals at example counter.

ahead at 3 min per passenger plus 3 min to serve the sixth). The six passengers share the queue area in front of the counter—60 ft²—with 10 ft² per person. Queue length declines during the rest of the hour.

If the competitive stance of the airline using this counter requires relatively high levels of service—for example, that passenger time at the counter (including waiting in queue) not exceed 12 min—then a second counter position may be required. Further, suppose that the airline believes that passengers waiting for service should not be so crowded that they have less than 10 ft² per person. This space standard is violated when more than six people are in the queue. At a service time of 3 min per passenger, only four people can be in the queue if a maximum wait time of 12 min is to be maintained. Some passengers will have to be served at another counter if an acceptable service level is to be maintained. The time standard becomes effective with the twelfth passenger and remains a constraint until the arrival rate declines and allows the agent at the counter to catch up. Two more passengers arrive during this period and cannot be served. The achievable service volume is then only 18 passengers in the peak hour at the target service level and subject to the given demand pattern.

RESEARCH NEEDS

Because airline practices vary so much, limited data are available on service times and on how counter and queue configuration can improve service times. More information in this area would give airlines and airport management a basis for assessing space needs and for working together to ensure efficient use of available terminal lobby areas.

NOTE

1. Subsections correspond to Steps 3, 4, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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1. P. Mandle, F. LaMagna, and F. Whitlock. *Collection of Calibration and Validation Data for an Airport Landside Dynamic Simulation Model*. Report TSC-FAA-80-3. Federal Aviation Administration, U.S. Department of Transportation, April 1980.
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11
Terminal Curb

Most passengers, their baggage, and sometimes accompanying visitors are dropped off or picked up at the terminal building curb frontage. In this area passengers leave ground transportation (automobile, taxi, bus, limousine, or courtesy van) and become pedestrians on their way to or from the aircraft gate.

DESCRIPTION

A variety of pedestrians, private automobiles, taxis, buses, commercial delivery trucks, and hotel and rental car courtesy vans use the terminal curb area. Passengers may be carrying luggage to or from the terminal building, checking luggage at curbside facilities, and waiting for access to taxis or other vehicles. At some airports passengers must cross frontage roads to reach parking areas from the terminal curb, slowing vehicular traffic circulation.

The principal demand and operating factors influencing service level and capacity for the terminal curb are summarized in Table 11-1. The primary determinant in the amount of curb frontage space required at a terminal is the length of time that vehicles stop for loading and unloading, referred to as the dwell time. For example, terminal designers estimate that reducing the average dwell time of those automobiles and taxis stopping at the terminal curb from 120 to 90 sec can increase the capacity of a curb area by 15 to 20 percent *(1)*. Dwell time is influenced by whether drivers stop and leave their vehicles to accompany passengers into the terminal building or to meet or find an arriving passenger. Airports may seek to limit dwell times and overall congestion in the curb area through enforcement of regulations on access and by using signing and traffic management to separate user groups having substantially different demand characteristics. As an airport grows, parking and leaving vehicles along terminal curbs may be prohibited and efforts to channel

TABLE 11-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF TERMINAL CURB

Factor	Description
Available frontage	Length of curb frontage modified by presence of obstructions and assigned uses (e.g., airport limousines only, taxi only), separation of departures and arrivals
Frontage roads and pedestrian paths	Number of traffic lanes feeding to and from frontage area; pedestrians crossing vehicle traffic lanes
Management policy	Stopping and dwell regulations, enforcement practices, commercial access control, public transport dispatching
Passenger characteristics and motor vehicle fleet mix	Passenger choice of ground transport mode, average occupancy of vehicles, dwell times at curb, passenger patterns of arrival before scheduled departure, baggage loads
Flight schedule	Basic determinant of number of people arriving and departing at given time in given area

automobile traffic directly to parking areas may be made. At large airports already practicing strict enforcement of traffic regulations, physical design changes often are the principal means for dealing with curb congestion. However, curb access is in general a major policy issue, requiring a balance among concerns of commercial operators and private automobile users, access service levels, and safety. The policy issue at many airports extends well beyond the technical questions of curb frontage design and vehicle demand characteristics.

DEMAND PATTERNS

Because private automobiles are the dominant ground access mode at most airports, they are the principal source of terminal curb frontage demand. Such demand can be reduced at some airports by increasing availability of convenient parking, which typically raises the proportion of motorists who enter or exit parking areas directly without stopping at the curb frontage, or by encouraging passengers to use off-airport check-in facilities if these are available.

Demand for curb frontage is also determined by flight schedules and particularly by the arrival pattern of originating passengers (how far in advance of the scheduled departure time they arrive at the airport) and the route through the terminal of terminating passengers (how long it takes them

to travel from an arriving flight to the curb). Type of flight and trip purpose also influence terminal curb demand. For example, originating passengers on international flights are requested to arrive at the airport earlier than those aboard domestic flights. Terminating international passengers also are typically slower than domestic passengers to reach the curb frontage because of required customs and immigration procedures.

Passengers on business trips arrive at the airport closer to their departure time than those traveling for recreation or vacation. Deplaning business passengers, who may carry all their baggage aboard an aircraft and thus not need to stop at the baggage claim, reach the curb frontage sooner than those deplaning passengers who have checked bags.

Transfer passengers at some airports use buses operating on frontage roads and thus also contribute to the demand on terminal curb facilities.

The curb frontage demand resulting from shuttle buses and courtesy vans may be related to the number of trips per hour they make to the terminal and not directly to number of passengers. The operators of these vehicles, seeking to ensure that all passengers are picked up promptly and reliably, may provide frequent service operated on specific headways and allow some vehicles to be underutilized in order to reduce waiting time for their patrons.

Vehicle dwell time varies with type of vehicle, number in the vehicle, and baggage loads of passengers. Dwell times for originating (enplaning) passengers, as shown in Table 11-2, are typically shorter than those for terminating (deplaning) ones.

OPERATING CHARACTERISTICS

An airport operator may influence curb frontage operations primarily through traffic management, development and enforcement of regulations on access to and use of the terminal curb, and minor modifications of the basic design of the terminal curb frontage. For example, passenger arrivals and departures may be physically separated. Some terminals are designed initially or are retrofitted with two levels, an enplaning area on one level and deplaning on the other level. Some airports use signing on frontage roads to segregate arrivals and departures; vehicles meeting arriving passengers are concentrated in the vicinity of building exits and close to baggage claim areas. Different types of vehicles may also be segregated: commercial vehicles (buses, taxis, courtesy vans, and scheduled limousines) may be separated from private automobiles. Enforcement of regulations limiting vehicle dwell times in curb frontage areas influences traffic congestion, curb service levels, and capacity.

TABLE 11-2 OBSERVED CURB DWELL TIMES AT SELECTED AIRPORTS *(2–4)*

Airport	Average Dwell Time (min)
Miami International *(2)*	
Enplaning	1.6–4.5
Deplaning	2.3–4.5
Denver Stapleton *(2)*	
Enplaning	1.2–2.8
Deplaning	4.8–6.9
La Guardia, main terminal *(2)*	
Enplaning	1.0–1.6
Deplaning	2.1–4.8
Suggested representative statistics *(3)*	
Automobile	
Enplaning	1–3
Deplaning	2–4
Taxi	
Enplaning	1–2
Deplaning	1–3
Limousine	
Enplaning	2–4
Deplaning	2–5
Bus	
Enplaning	2–5
Deplaning	5–10
John F. Kennedy International (deplaning only, two unit terminals) *(4)*	
Automobile	1.2–1.9
Taxi	0.4–1.3
Greater Pittsburgh International (deplaning or enplaning) *(4)*	
Automobile	1.0–2.4
Taxi	0.8–1.3

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

Analyses of the terminal curb sometimes use procedures adapted from traffic engineering. Simplified planning models such as that developed by Mandle et al. *(5)* relate traffic volumes and service levels to available curb length appropriately corrected for specific operational and physical characteristics of the airport. Service levels are analogous to those defined in TRB's *Highway Capacity Manual (6)*. The Canadian government uses similar analysis procedures to calculate an effective curb utilization rate reflecting the estimated fraction of time that the available curb is occupied *(7)*.

A primary element of terminal curb service level is the motorist's ability to find a space for loading or unloading. The probability of a motorist's finding

an empty curb space or having to double park is typically used to describe service level, although other parameters such as general traffic congestion may be used as indicators of this probability. During the busiest periods some degree of double parking is considered acceptable at many airports.

It is important to note that the capacity of the terminal curb lane is distinct from the capacity of the travel lanes adjacent to it. These travel lanes are part of the ground access component (Chapter 13).

EXAMPLE OF ASSESSMENT PROCESS[1]

Suppose that frequently recurring congestion in front of the terminal building at a medium hub airport (served by four airlines) has caused consideration of a new roadway design to increase available curb frontage. Before hiring a consultant, management would like to know whether service levels can be improved and new construction avoided by better utilization of existing facilities.

Describe Component

The single-level terminal building is 400 ft long with a sidewalk and a loading and unloading lane adjacent to a two through lanes (Figure 11-1). Extensions of sidewalk beyond the ends of the terminal building bring the total curb frontage to approximately 460 ft. The terminal building has three entrances spaced at intervals of approximately 100 ft, and serving both arriving and departing passengers.

Describe Demand and Operating Factors

There are 16 scheduled aircraft operations (arrivals and departures) during the peak periods with total seat capacity of approximately 1,700 passengers, and average load factors are 62 to 78 percent. Approximately 85 percent of the passengers originate or terminate their journeys during these periods. Departures represent approximately 55 to 60 percent of the passengers during the morning early in the week and during the afternoon in the latter part of the week. Arrivals represent a similar majority during other daily peak hours.

The airport operator has never surveyed passenger ground transportation characteristics, but a staff analyst estimates that 90 to 95 percent travel by private automobile, and 3 to 6 percent by rental car. There is taxi service but virtually no airport van or bus service.

The curb frontage is unregulated with respect to passenger loading and unloading. Passengers try to stop as close as possible to the door serving their

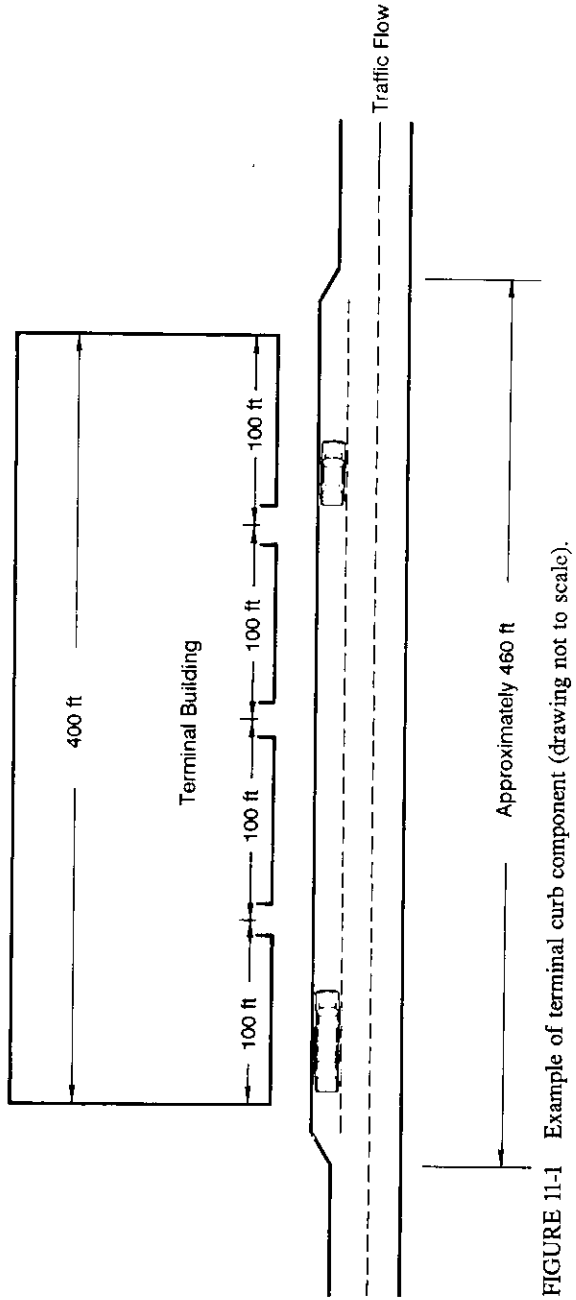

FIGURE 11-1 Example of terminal curb component (drawing not to scale).

airline. Drivers awaiting arriving passengers typically park along the curb and even leave their vehicles, although there is a traffic regulation prohibiting parking. Eight to 12 cars may be parked in this way on a typical Thursday or Friday afternoon. A few commercial delivery vehicles may also be seen in the traffic stream and at the curb.

Estimate Service Levels and Service Volumes

Using the figures available, total peak-hour passenger load is estimated:

$$\begin{aligned}\text{Total passenger load} &= (\text{seats}) \times (\text{load factor}) \times (1 - \text{percentage of transfers}) \\ &= (1{,}700) \times (62 \text{ to } 78 \text{ percent}) \times (85 \text{ percent}) \\ &= 900 \text{ to } 1{,}130 \text{ passengers in the peak hour}\end{aligned}$$

With a directional split of 55 to 60 percent in the peak hour, the estimate is carried further:

$$\begin{aligned}\text{Enplaning passengers (or deplanements)} &= (55 \text{ to } 60 \text{ percent}) \times (900 \text{ to } 1{,}130) \\ &= 500 \text{ to } 680 \\ \text{Deplaning passengers (or enplanements)} &= (40 \text{ percent to } 45 \text{ percent}) \times (900 \text{ to } 1{,}130) \\ &= 360 \text{ to } 510\end{aligned}$$

Because this is a medium hub airport and so heavily automobile-oriented, the average number of passengers per vehicle is assumed to be low, about 1.05. Noting that the parking lots at the airport are seldom full and observing that many passengers are dropped off or picked up by family members, the analyst estimates that approximately 70 percent of the vehicles going in the peak direction use the curb.

Using definitions of service level as adopted by Mandle et al. *(5)*, the analyst observes that level-of-service D or E appears to occur during the morning and afternoon peak hours 3 to 5 days each week and operational problems are frequent. Management would like to ensure that conditions are stable for all but the busiest times at level-of-service C or better.[2]

Using the procedure developed by Mandel et al. *(5)*, curb requirements may be estimated for the situation just described. This procedure indicates that with best-case base estimates of service volume of 500 to 680 enplaning passengers, approximately 240 to 300 ft of curb frontage is needed to maintain level-of-service C (Figure 11-2).

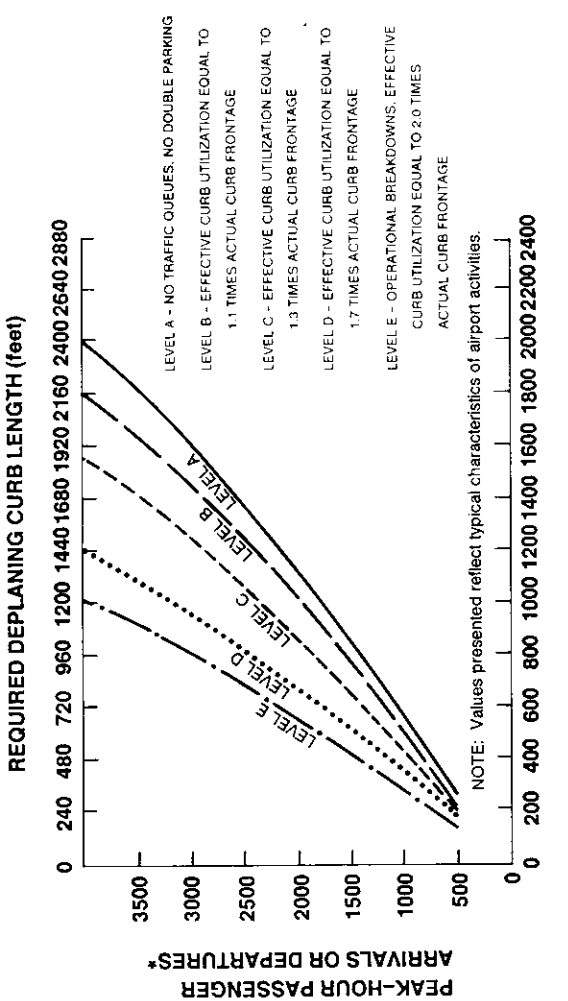

FIGURE 11-2 Suggested method for estimating curb frontage needs *(5)*.

Although the deplaning passenger level is less than the lower limit of the graph, a rough estimate might be made that for 360 to 510 deplaning passengers 200 to 240 ft of curb frontage is needed. The total base estimate in Figure 11-2, 440 to 540 ft, might be increased 25 to 35 percent to account for low average vehicle occupancy. On balance, the analyst might conclude that the airport should have 550 to 700 ft of curb to maintain level-of-service C. Reversing the same procedure, the model confirms that level-of-service E or worse can be expected given the combination of estimated demand patterns and current curb frontage.

However, no consideration was given in the analysis to the impact of parked vehicles, which at times fill 40 percent of the curb frontage. Given the uncertainty and level of detail of the analysis, the estimated terminal curb requirements are not so much greater than what is available (at worst, 50 percent greater need than availability), and because conditions are observed to be in the level-of-service D to E range, management might justifiably expect that enforcement of the existing traffic regulations might bring the service level up to target. Such a solution might be worthy of a trial while data are gathered to support consideration of more costly construction alternatives.

RESEARCH NEEDS

The levels of understanding and assessment procedures for the terminal curb are well developed in comparison with those for other components of the landside. Although models of the sort used in the preceding example are helpful and might warrant further expansion, the underlying principles are based on traffic analysis and are less in need of research. Nevertheless, professionals in the field have observed that local idiosyncrasies of driver behavior and roadway geometry can have substantial impact on curb performance, and that operational changes can relieve many problems. There may then be benefits to increased publication of good solutions to existing problems, which may suggest what might work for other airports with similar curb frontage situations.

NOTES

1. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6). Other examples of assessment have been published by Tilles *(4)*, Mandle et al. *(5)*, and Hart *(8)*.
2. Service levels are defined generally in the *Highway Capacity Manual (6)* as follows:

C–Stable flow, but the beginning of the range of traffic flow in which operation of individual users becomes significantly affected by the presence of others and maneuvering within the traffic stream requires substantial vigilance on the part of the user. The general level of comfort and convenience declines noticeably at this level.

D–High-density but stable flow. Speed and freedom to maneuver are severely restricted. Small increases in traffic flow will generally cause operational problems.

E–Freedom to maneuver within the traffic stream is extremely difficult. Comfort and convenience levels are extremely poor. Operations at this level are usually unstable because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.

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12
Parking Area

Parking areas consist of surface lots or multilevel garages used to store the vehicles of air passengers and visitors. Although parking and storage areas are also needed for employee vehicles, rental cars, taxis, and buses, these requirements have relatively little influence on the capacity or service level of the airport as viewed by a passenger. The focus of this section is therefore public parking.

DESCRIPTION

For planning purposes, parking is divided into two or three general categories: short-term, long-term, and remote (which is usually long-term parking). Short-term parking is usually located close to terminal buildings and serves motorists dropping off or picking up travelers. These motorists usually remain at the airport for less than 3 hr. Some airports distinguish other periods of time as "short term." The most expensive parking is often found in the short-term lots.

Long-term parking serves passengers who leave their vehicles at the airport while they travel. With the low turnover rate and long duration of stay, long-term parking accounts for 70 to 80 percent of the occupied parking spaces at an airport, even though only 15 to 30 percent of all vehicles parked over the course of a year is represented *(1)*.

Remote parking consists of long-term parking lots located away from the airport terminal buildings. Often buses or vans may be available to transport passengers to the terminal. At some airports these parking facilities are called

shuttle lots or, when used only during peak periods, holiday lots. Because parking rates at remote lots are less expensive than those for other airport parking facilities, these lots are often termed "reduced-rate" parking.

Entry to airport parking areas is usually controlled by automatic gates, and parking fees are collected by a cashier located in a booth at the exit. At some airports motorists leaving the parking facilities are delayed because there are insufficient cashiers.

In addition to delays encountered entering and leaving parking areas, passenger service levels will also be affected by the distance to be walked between parked vehicles and the terminal and by the environment in which this walk occurs. At some airports weather-protected walkways improve passenger assessment of the service level. Other airports provide escalators, moving sidewalks, buses, people movers, or other mechanical assistance to reduce passenger walking distances and number of level changes.

The principal demand and operating factors influencing service level and capacity for parking areas are given in Table 12-1. Although the number of parking spaces provided is a snapshot measure of capacity, the total time required for access and egress influences the assessment of service level provided. Such factors as the allocation of parking between short- and long-term uses and parking prices influence service levels.

DEMAND PATTERNS

Demand at parking areas is characterized by accumulation of parked vehicles, which is measured by both length of time as well as number of parking spaces occupied. This accumulation is influenced by passenger arrival times at the airport and trip purposes. Business travelers have been found to be less sensitive to parking costs than those on pleasure trips and thus more likely to use more expensive, close-in, short-term parking. Passengers on vacation are more cost sensitive but value their time less. They are more likely to seek reduced-rate, remote parking areas. Passengers who expect to be away for long trips have greater amounts of baggage and are more likely to be dropped off or greeted by motorists who use short-term parking.

Parking demand is in general very sensitive to the cost of parking. Effective parking capacity can be increased by altering parking fees to increase the cost difference between short-term and long-term parking and thus encourage price-sensitive motorists to divert to less expensive parking areas. General increases in parking fees may also encourage passengers to choose other means than driving their own automobiles for their trip to the airport.

Parking space needs are determined primarily by the amount of long-term parking, because it generates the most space-hours. Because of their higher

TABLE 12-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF PARKING AREAS

Factor	Description
Access (enplaning)	
Available space	As a function of distance from terminal area, systems for reaching terminal, prices for parking, and availability of weather-protected waiting and walking areas
Access times	Total, including search for space, wait, and travel from remote locations
Passenger characteristics	Percentage of people driving, automobile occupancy, visitor ratios, length of stay
Pricing	Higher fees may suppress demand or divert some to lower-cost lots
Flight schedule	Basic determinant of number of people arriving at parking areas
Egress (deplaning)	
Access time	Total, including wait and travel to remote locations, with consideration for availability of weather-protected wait and walk areas
Exit position and employee efficiency	Number and direction to exits, service times to exit lots
Passenger characteristics	Fraction driving, automobile occupancy, length of stay
Flight schedule and load	Basic determinant of number of people arriving at parking areas

turnover rate, short-term spaces generate more entry and exit movements than do long-term spaces. Demand for automatic gates at the entry and cashier booths at the exit of the parking area is a function of the number of entries and exits, which, although not indicative of space needs or parking demand, may be significant for capacity estimation.

The number of parking spaces required to provide adequate service levels is normally greater than total parking demand. This is because at a large parking facility in which many areas cannot be seen simultaneously, for example, in a multilevel garage or extensive open lot, it is more difficult to find the last empty spaces. Thus a large parking facility may be considered full when 85 to 95 percent of the spaces are occupied, depending on its use by long- or short-term parking, size, and configuration.

OPERATING CHARACTERISTICS

The balance between long- and short-term parking is critical to capacity estimation. As already noted, distribution of demand may be significantly

influenced by parking fees. For example, when New York City's LaGuardia was faced with a serious shortage of parking space, structured parking facilities were constructed, and all parking rates were raised significantly to substantially reduce long-term parking at the airport and make space available to satisfy short-term demand. Such a strategy generally requires that adequate alternative transport services be available to meet the demand for airport ground access.

Besides determining number of parking spaces available and the effective distance of spaces from terminal buildings, parking operators may be able to adjust the physical design of the parking lot entries and exits to reduce or avoid congestion and use informational signing to direct motorists to underutilized facilities. However, lengthening the pedestrian path between the parking lot and the terminal may reduce overall perceived service levels. Some airports are experimenting with "pre-cashiering," in which passengers pay their parking fees before entering their vehicles, as a means to reduce delay and congestion at exit plazas.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

A variety of rules of thumb and computational procedures have been developed to estimate parking space requirements at an airport. Indexes of spaces per annual or average monthly enplaned passenger are frequently used in planning:

Source	*Index*
Roads and Transport Association of Canada *(2)* (smaller airports)	1.5 spaces/peak-hour passenger; 900 to 1,200 spaces/million annual enplaned passengers
FAA *(3)* (non-hub airports)	Approximately 1 space/500 to 700 annual enplaned passengers

Because transfer passengers do not create parking demand, indexes based on originating passengers only (Figure 12-1) are likely to be most meaningful. Used together with local experience or rules of thumb relating annual passenger loads to total parking demand, such indexes may be used to judge the likelihood that the number of parking spaces available at an airport is appropriate to current or anticipated levels of demand. However, such calculations do not give true service-level indicators.

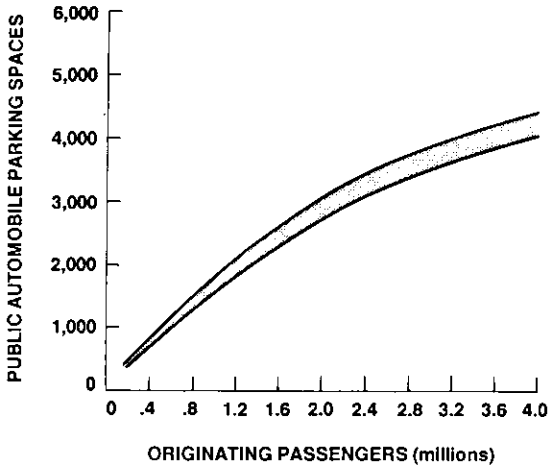

FIGURE 12-1 Estimated requirements for public parking at U.S. airports *(4)*.

Mathematical simulation has been used to model parking accumulation *(1)*. Detailed information on time of arrival and departure of automobiles relative to scheduled flight times and duration of stay relative to parking cost and distance from the terminal are generally required. Trip purpose and traveler income data may also be useful for estimating sensitivity of passenger ground transport mode and parking location choice to parking fees. Useful data and analysis procedures may be available through the local transportation agency.

Peak-period conditions at entry and exit of the parking lot may be observed in field surveys or estimated as queueing problems. Likely levels of demand at cashier exits may be forecast from flight arrival schedules, with assumptions about the time it takes passengers to reach their vehicles after a flight has landed.

Time required for passengers to locate a parking space and walk or ride to or from the terminal building and the conditions under which passengers must make this trip are important elements of service level. Typical parking area travel and service time parameters at a number of airports are summarized in Table 12-2. However, actual field data are not available to compare these elements from a variety of airports. Some airports try to maintain a maximum walking distance of 800 ft between parking lots and airport terminal buildings and provide bus service for parking beyond that distance. Other airports might find this distance inappropriate.

TABLE 12-2 PARKING-AREA TIME PARAMETERS AT SELECTED AIRPORTS

Parameter	Time (min)
Walk from terminal to parking, BWI[a]	6.4
Walk, wait, and ride shuttle from terminal to parking, BWI[a]	8.6
Search for parking space following entry to lot, BWI[a]	1.4
Automatic ticket dispenser service *(1)*	0.15–0.16
Parking lot exit booth service	
Miami International *(5)*	0.5
Denver Stapleton *(5)*	0.5
New York La Guardia *(5)*	0.2–1.1
Typical *(1)*	
Single fee policy	~0.24
Variable fee policy	0.5–0.6
Drive from space and exit, Tampa International[a]	4.5

NOTE: BWI = Baltimore-Washington International.
[a]Reported by airport management.

EXAMPLE OF ASSESSMENT PROCESS[1]

Suppose that an airport with annual traffic of approximately 5 million passengers expects a new airline to begin operations in the near future. Management is concerned that parking capacity may be insufficient to meet this demand and wants to be prepared to take corrective or preventive action.

Describe Component

The airport currently has a total of 2,200 parking spaces available and finds that lots close to the terminal building—for both short-term and long-term parking—are 75 to 90 percent filled between Tuesday afternoon and Thursday afternoon almost every week. Remote lots, which contain 600 spaces and are used primarily for long-term parking, are seldom more than 50 percent full.

Describe Demand and Operating Factors

Approximately 70 percent of annual enplaned passengers are originations. There have been no recent surveys of passenger access modes, but management estimates that perhaps 55 percent of the business-traveler market served by the new airline will choose, if possible, to drive and park at the airport and that the average duration of trips will be approximately 2 days.

The new airline is expected to offer six flights a day, serve primarily originating passengers, and use aircraft with a seating capacity of 100 to 130 passengers.

Long-term parking rates are currently set at $2.00 per hour or fraction with a daily maximum of $6.00. Short-term rates are $1.00 per 1/2 hr or fraction with a daily maximum of $24.00. Long-term remote lots charge $1.00 per hour or fraction with a daily maximum of $4.00 and are linked by bus to the main terminal.

Estimate Service Levels and Service Volumes

Because close-in long-term lots are nearly full midweek, there may indeed be a need for more parking. However, there are at least 300 spaces potentially available in the remote lots. In an effort to maintain the overall service level, the airport management would like to add capacity to accommodate demand at least above current levels and to maintain this condition as demand grows. Current midweek space needs are estimated as follows:

Current space needed = (filled spaces) × (115 percent allowance for service level)
= (2,200 − 300) × (115 percent)
= approximately 2,200 spaces

That is, current parking capacity is apparently just equal to demand given the desired service level.

The parking supply of 2,200 spaces represents an average rate of 0.63 space per 1,000 enplaning passengers at the airport. If all new passengers are assumed to be originating or terminating their trips, 150,000 to 195,000 new enplaning passengers are expected annually. Maintaining the level of parking supply at this rate would then require 94 to 123 new parking spaces.

Assuming that the new airline can achieve perhaps a 70 percent load factor, six flights a day with 100 to 130 seats per flight may represent new traffic of 300,000 to 390,000 passengers annually, most of whom are expected to be originating or terminating their trips.

Because spaces are available only at remote locations and the new airline is serving business travelers, who are normally willing to pay premium prices to park, consideration might be given to raising parking fees at nearby lots. The increased fees might shift some travelers to other access modes (perhaps putting some pressure on terminal curb facilities), but probably would improve utilization of remote lots and generate additional revenue.

RESEARCH NEEDS

Additional data on parking access, search, and time and on times and distances passengers must travel from parking areas to terminal buildings would be useful to support service level assessments. Research on the degree to which parking service levels and cost can influence choice of modes for travel to the airport would also be useful for capacity management.

NOTE

1. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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13
Ground Access

The roadways for access and circulation and public and private transit—both on and off the airport—make up the ground access system. When available, off-airport passenger check-in facilities or downtown terminals form part of this system. Typically only those off-airport elements of ground access that serve significant volumes of airport traffic are considered in planning and analysis. For example, a particular intersection far from the airport may be a constraint for one passenger but will have no material impact on airport operations. For many airports the access system extends only to the nearest interchange or intersection, whereas at those airports where most passengers arrive via a single primary route (such as the Sumner-Callahan tunnels in Boston or the expressway leading to Dulles International in Washington, D.C.) the access system may include many miles of a particular roadway or transit line.

DESCRIPTION

Ground access is provided by an assortment of private and public transport modes. Except in those few cases where a rail transit system serves the airport, these ground access modes all use the metropolitan highway and street network and share the same roadways for circulation at the airport. For the three airports shown in Table 13-1, as at most U.S. airports, private automobiles and taxis are the principal access modes used.

Those accompanying or meeting passengers influence the demand on ground access systems. Such individuals overwhelmingly travel by private

TABLE 13-1 GROUND ACCESS MODES OF PASSENGERS AT SELECTED AIRPORTS *(1)*

	Percent Choosing Mode by Type of Passenger					
	Originating			Terminating		
Access Mode	Miami	Denver	La Guardia	Miami	Denver	La Guardia
Private automobile	42	56	25	47	70	31
Rental car (van)	11	14	9	20	8	4
Taxi	22	14	46	18	10	35
Limousine	10	5	13	10	5	20
Bus	15	3	5	5	5	5
Other	0	9	2	0	3	5

NOTE: Percentages may not add to 100 because of rounding.

TABLE 13-2 GROUND ACCESS MODES OF THOSE ACCOMPANYING PASSENGERS AT SELECTED AIRPORTS *(1)*

	Percent Choosing Mode by Type of Passenger					
	Originating			Terminating		
Access Mode	Miami	Denver	La Guardia	Miami	Denver	La Guardia
Private automobile	99	80	82	84	97	90
Rental car (van)	1	–	–	6	2	1
Taxi	–	7	9	5	1	5
Limousine	–	–	9	3	–	1
Bus	–	7	–	2	1	1
Other	–	7	–	–	–	3

NOTE: Percentages may not add to 100 because of rounding.

automobile, as do airport employees (Table 13-2). Additional vehicle trips result from the delivery of cargo, priority packages, mail and terminal building and concession supplies and the numerous service and maintenance requirements of an airport. The peak hours for employee and other highway travel not related to the airport and the conditions on the on-airport roadways most heavily used only by employees and airport operations differ from those for passenger traffic and are not addressed here.

The principal demand and operating factors influencing capacity and service conditions for ground access are summarized in Table 13-3. Although it is often necessary to view many of these factors on a metropolitan scale, the focus of capacity assessment is on the service provided between the terminal curb or parking area and the interchange linking the airport with the regional transportation system.

TABLE 13-3 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF AIRPORT GROUND ACCESS

Factor	Description
Available modes and prices	Connections from various parts of the metropolitan area served, considering prices, comfort, and convenience, particularly with respect to baggage and required vehicle changes
Access times	Total, including wait for vehicles or access and travel from representative locations
Passenger characteristics	Fraction choosing each mode, vehicle occupancy, number of people accompanying passenger, other visitors, baggage loads, origination/destination share
Vehicle operator behavior	Fraction going directly to curb or to parking, weaving, curb dwell time, knowledge of traffic patterns
Flight schedule and load	Basic determinant of number of people using ground facilities
Facilities and background traffic conditions	Highway and transit routes, interchanges; levels of traffic on facility for other than airport purposes; availability of remote check-in facilities

DEMAND PATTERNS

Access demand is primarily determined by the travel modes selected by passengers and visitors, the number of persons per vehicle (Table 13-4), the circulation patterns of these vehicles, and how long before or after a flight a person arrives at or leaves the airport. Demand patterns of courtesy vehicles and scheduled limousines and buses may not be directly related to air passenger activity patterns. Access demand is influenced by the extent of the public transportation system available, passenger trip purpose, the availability of parking, type of flight, and availability of alternative check-in areas. Cost of parking can have a particularly significant impact on access mode choice at large airports.

Ground access demand is generated by both originating and terminating passengers. At airports with multiple terminal buildings the volume of connecting passenger transfers may influence the need for terminal-to-terminal shuttle bus service. At other airports passenger transfers do not leave the terminal building and do not affect demand for either access or circulation. Circulation patterns are influenced by the location of the entrance and exit to parking and rental car areas, the availability and location of a recirculation road, the cost of short-term parking, and configuration of the terminals (single or multiple).

TABLE 13-4 TYPICAL AVERAGE VEHICLE OCCUPANCY RATES FOR AIRPORT GROUND ACCESS *(2)*

Access Mode	No. of Passengers per Vehicle
Private automobile	1.9
Rental car	1.2
Taxi	2.5
Limousine	5.6
Other	4.2

OPERATING CHARACTERISTICS

Driver familiarity with the roadway system and the complexity of the system significantly influence ground access operations. Complex road systems, such as those often found at large airports, require quick decision making by motorists unfamiliar with the airport and often involve frequent merging and weaving. Traffic control devices at at-grade intersections also influence system performance.

The management of taxi, limousine, and courtesy bus operations may also influence ground access operations. Control of taxi entry to the terminal area, issuance of taxi permits for airport service, and encouragement of limousine services are among the actions taken by management at some airports to improve ground access conditions. Control of cargo vehicles and employee access are also important at some airports.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

The airport's road access facilities may be analyzed on the basis of standard traffic analysis procedures such as those presented in the TRB *Highway Capacity Manual (3)*. The service-level descriptions and capacity analysis procedures described in the manual may be used to address airport ground access capacity. More specialized advice, including worksheets to guide analysis, is given in the FAA's *Airport Ground Access Planning Guide (4)*.

For many purposes, approximations of capacity may be adequate. Average hourly volume of service roadways of typical facilities at *Highway Capacity Manual* level-of-service C and D is summarized in Table 13-5. The breadth of these ranges makes such approximations useful primarily for initial testing for problems.

TABLE 13-5 GROUND ACCESS FACILITY VOLUME *(3)*

Facility Type	Average Hourly Volume[a] (vehicles/hr/lane[b])
Main-access and feeder freeways (controlled access, no signalization)	1,000–1,600
Ramp to and from main-access freeways, single lane	900–1,200
Principal arterial (some cross streets, two-way traffic)	900–1,600
Main-access road (signalized intersections)	700–1,000
Service road	600–1,200

[a]Highway level-of-service C and D (see Chapter 11).
[b]Passenger-car equivalents.

Analysis of the demand on a typical airport access system can be accomplished by estimating separately the vehicle trips (on each road link) associated with arriving passengers, departing passengers, visitors, employees, service vehicles, empty taxicabs, and courtesy vehicles and then combining these volumes. Peak periods for regional traffic using airport access facilities should be considered as well as peak periods for passenger traffic.

EXAMPLE OF ASSESSMENT PROCESS[1]

Suppose that a small hub airport is competing to attract an airline hub operation. There is some concern that traffic growth may overburden the four-lane arterial serving the airport.

Describe Component

The access road is a major arterial within the urban region and serves some local traffic. Existing traffic volumes are estimated by the city traffic engineer's office to be approximately 1,400 vehicles per hour in the direction of peak flow, which coincides with that of airport passengers.

Describe Demand and Operating Factors

Current demand is the same as that described for the analysis of the terminal curb in Chapter 11. Estimated peak-hour passenger volumes are 500 to 680 passengers in the peak direction, and peak airport road demand is estimated to

be currently 480 to 650 vehicles per hour, or approximately 35 to 45 percent of the access road's volume. These estimates may be considered somewhat low because they were developed without detailed consideration of buses, commercial vehicles, and other traffic not generated by air passengers. Such traffic typically is a significant part of access demand.

General community growth is projected to continue at approximately 2.5 percent annually for the next 5 years, so that background traffic (e.g., traffic using the highway but not related to the airport) on the road may increase 13 percent over that period, regardless of airport growth:

$$\begin{aligned}\text{Future background traffic} &= (\text{growth rate}) \times [(\text{total traffic}) - (\text{airport traffic})] \\ &= (113 \text{ percent}) \times [(1{,}400) - (\text{airport traffic})] \\ &= 850 \text{ to } 1{,}040 \text{ peak-hour passenger cars in peak direction}\end{aligned}$$

The airport management hopes to achieve a growth of 30 percent in passenger traffic during that same period. Because airport employees report at different times due to passenger peaks, employee ground traffic will not make a significant contribution to access problems that may occur.

The access road is a typical urban arterial with signalized intersections and a moderate level of truck traffic. Levels of service are generally in the B to C range during the peak hour.

Estimate Service Levels and Service Volumes

Assuming no changes in the modes chosen for travel to the airport, growth of 30 percent would mean an increase to 620 to 850 vehicles per hour in the peak direction. Combined with projected background traffic, total volumes of 1,470 to 1,890 vehicles per hour are forecast. On the basis of *Highway Capacity Manual* information (Table 13-5), the capacity of the two inbound lanes of the main access road would be 1,400 to 2,000 vehicles per hour at service levels in the C to D range.

The capacity of the road therefore appears to be adequate to serve forecast traffic. However, because the analysis was based on assumptions with little supporting information, the city traffic engineer is called in to explore whether signal timing, a reversible lane scheme, or some other transportation system management action might be taken to relieve congestion problems if they develop as traffic grows.

RESEARCH NEEDS

Methods and standards for characterizing ground access conditions are relatively well developed in comparison with those for other components of the terminal landside. However, data are still needed on how driver unfamiliarity with an airport and ability to understand complex roadway systems affect safety and capacity of an airport access system. Low-speed weaving patterns, which are peculiar to airports and similar facilities, are an aspect of traffic operations that merits particular attention.

There is also a need for airport-specific evaluations of the relative significance of ground access delays to air travel. Data from such evaluations would be useful to decision makers responsible for assuring an airport's effectiveness within the context of a regional economy.

NOTE

1. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

REFERENCES

1. P. Mandle, F. LaMagna, and E. Whitlock. *Collection of Calibration and Validation Data for an Airport Landside Dynamic Simulation Model.* Report TSC-FAA-80-3. Federal Aviation Administration, U.S. Department of Transportation, April 1980.
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14
Baggage Claim

Terminating passengers with checked luggage frequently judge their deplaning experience largely in terms of the service provided at the baggage claim. Delays at this area have encouraged many business travelers to carry all of their luggage on board, a practice that affects operations and capacity of other airport components such as security screening and passenger waiting areas.

DESCRIPTION

Baggage claim areas are typically located adjacent to the direct route of deplaning passenger circulation to provide an area suitable for an activity that involves waiting and heavy circulation. Often a physical barrier is used to separate the claim area from the rest of the terminal building.

The area may be leased exclusively to one or more airlines or may be operated by the airport. Although baggage handling equipment may be installed by the airport operator, baggage claim personnel are typically airline employees, and operations within the baggage rooms are normally managed by the airline. Airlines try to avoid significant crowding and delay primarily by staffing to meet demand levels.

The principal demand and operating factors influencing service level and capacity in the baggage claim are summarized in Table 14-1. Capacity over the short run—typically a period of 20 min to 45 min—is determined primarily by how many passengers can wait in the same area and the speed with which their luggage arrives and is displayed. Baggage handling equipment capacity is generally measured in terms of numbers of pieces of luggage that can be displayed in a given period of time.

TABLE 14-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF BAGGAGE CLAIM

Factor	Description
Equipment configuration and claim area	Type, layout, feed mechanism, and rate of baggage display; space available for waiting passengers; relation of wait area to display frontage; access to and amount of feed belt available
Staffing practices	Availability of porters (sometimes called "sky caps") and inspection of baggage at exit from claim area influence rates of exit; rate of baggage loading/unloading from cart to feed belt
Baggage load	Numbers of bags per passenger, fraction of passengers with baggage, time of baggage arrival from aircraft
Passenger characteristics	Rate of arrival from gate, ability to handle luggage, use of carts, number of visitors

DEMAND PATTERNS

The number of passengers waiting in the baggage claim depends on the rates at which passengers arrive from the gate and luggage is processed following arrival of a flight. Maximum demand levels are likely to occur during periods when arrivals of larger aircraft cause surges of passengers at the baggage claim. The impact of 300 passengers arriving on a single widebody aircraft is greater than that caused by the same number of passengers arriving on three separate smaller aircraft, because in the latter case, the arrival of both passengers and luggage at the baggage claim is typically spread over a longer period of time.

Airline operations serving long-distance, tourist, and vacation traffic will usually carry greater baggage loads than those serving primarily short-haul, business, and commuter markets. Introduction of new types of service can bring radical shifts in the demand on baggage claim facilities.

OPERATING CHARACTERISTICS

Baggage claim devices may serve two or more flights on one or more airlines. Devices are allocated to flights and airlines according to lease arrangements and demand.

Passengers typically form layers (very wide queues) around the baggage claim device, which tend to be deepest around the upstream end of the device and near the primary access point to the claim area. A row of passengers one to two deep has direct access to the claim device and will be able to see and reach their bags. Other passengers wait to gain access to this queue.

Bags are brought on carts from the arriving aircraft and placed on feed belts for transfer to the claim device display area. Rates at which bags are transferred from aircraft to carts and from carts to feed belt and times required to transport carts from the aircraft to the baggage claim area vary with airline operating practices, airport configuration, and operating congestion.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

Capacity of baggage claim areas is judged by considering the average time passengers must wait to retrieve their checked baggage and by comparing number of people in the claim area with the size of that area. Simple queueing analysis is often used to estimate the average time passengers will have to wait for bags and the number waiting. Planning and design standards are then selected, generally on the basis of square feet of floor area and linear feet of baggage display device per person.

There are no generally accepted industry standards for waiting times in baggage claim areas.[1] The guidelines and methods presented in the FAA-sponsored Parsons manual *(4)* are widely used.

In Table 14-2 commonly used guidelines for judging crowding are given. Short-term surges of crowding are typical of any baggage claim facility, and estimated (computed) average levels of crowding will typically decline as progressively longer periods of time are used in the analysis. For example, average waiting area available per person during a peak 20-min period might be only 40 to 60 percent of that available during the peak hour as a whole.

TABLE 14-2 PLANNING AND DESIGN GUIDELINES FOR BAGGAGE CLAIM

Typical Design Situation	Space Standard (ft^2/person)
IATA standards for claim area waiting *(3)*	
System breakdown	< 8.6 for more than 15 min
High to excellent level of service, comfort	> 15.1 at all times
FAA implied planning guideline *(4)* based on claim and wait queue 13 ft deep and approx. 2 passenger/ft display in peak 20-min period	~ 6.5 at all times

NOTE: IATA = International Air Transport Association.

Demands on the baggage claim may be characterized by using a baggage claim device schedule diagram (Figure 14-1), which is similar in nature to a ramp chart (see Chapter 6). This schedule diagram shows the times when

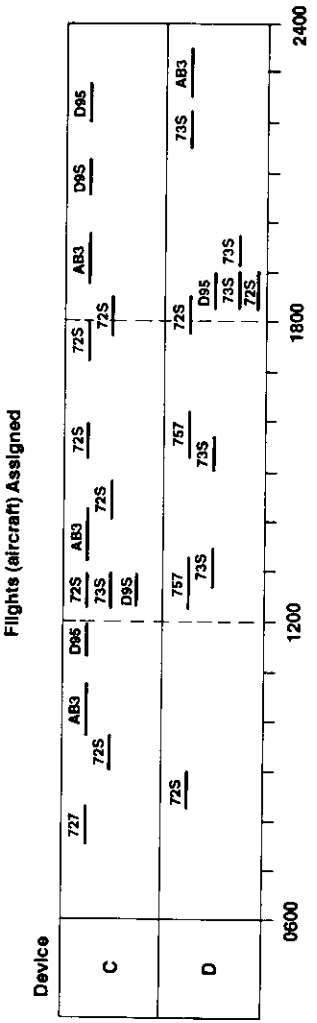

FIGURE 14-1 Example baggage claim device schedule diagram (*5*).

various flights are assigned to each claim device in a baggage claim. From such a diagram, it can be determined when or whether additional flights may be accommodated. When this diagram is used with a passenger arrival distribution and baggage delivery rates, congestion in the claim area can be determined.

For judgments about possible future conditions, mathematical queueing and simulation models have been developed to predict the arrival of deplaning passengers and baggage at baggage claim areas *(2)*. Such models and field observations may be used to develop standard distributions of passenger accumulation versus time for particular types of flights at a particular airport, taking into account relative rates of arrival of baggage and passengers. These standard distributions may then be used to approximate expected conditions if new services are introduced or new facilities are being planned.

EXAMPLE OF ASSESSMENT PROCESS[2]

Suppose that an airline has started service at an airport in which the passenger travel distance between gates and baggage claim is shorter than usual. The airlines and the airport operator have been receiving passenger complaints about the length of time they must wait for baggage. Management wants to explore whether new baggage handling equipment may be needed to improve service.

Describe Component

A single baggage claim serves flights arriving at three gates, the walking distance between the claim area and each gate ranging from 150 to 300 ft. The baggage claim device is circular, 25 ft in diameter, and located within a square enclosure approximately 50 ft on each side (Figure 14-2).

Describe Demand and Operating Factors

The flights at this airport have passenger loads of 100 to 160 people, 90 percent of whom have checked baggage. The average baggage load for those with checked luggage is 1.3 bags per passenger. During the peak period of activity, three flights land at 10-min intervals.

The claim device delivers 15 bags per minute to the carousel. It usually takes 7 min from aircraft arrival until the first bags arrive at the claim area.

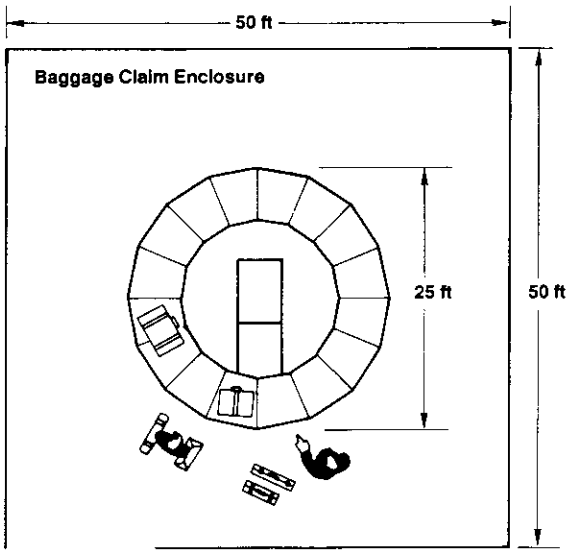

FIGURE 14-2 Baggage claim example.

Passengers normally begin to leave the aircraft within 2 min and walk to the baggage claim area.

Estimate Service Levels and Service Volumes

The physical capacity of the system to deliver baggage is determined by the claim device. With current operating practice, the minimum processing time for a single flight may be estimated:

Min. process time = (time for first bag to arrive) + [(no. of bags)/(avg. delivery rate)]
= 7 + {[(100 to 160 pax.) × (90 percent) × (1.3)]/(15 bags/min)}
= 7 + (7.8 to 12.5) = 15 to 19 min

If passengers walk at 180 to 280 ft/min, then the expected time of arrival of the first passenger at the baggage claim may be estimated as follows:

First passenger's arrival = deplane time + walk time
= 2 + [(150 to 300 ft)/(180 to 280 ft/min)]
= 2.5 to 4.7 = 3 to 5 min

Expected maximum passenger wait time is then the difference between the time of the first passenger's arrival and first bag arrival plus one-half of the delivery time, or 6 to 11 minutes. Average passenger wait time is 2 to 7 min.

At a second airport, the only other one in the region, passengers walk an average distance of 850 ft to the baggage claim area in perhaps 3 to 5 min. With the same deplaning procedures, passengers at the second airport begin to arrive at the baggage claim areas 5 to 7 min after the flight's arrival. Expected maximum wait time is estimated as only 3 to 8 min (i.e., 0 to 2 min for the first bag plus an average 3 to 6 min for a particular bag to arrive).

It thus appears that service levels at the first airport are even lower than they are at the second airport and that passenger complaints may stem largely from their enhanced perception of the wait, which is based on their experiences at the second airport. Further, the range of time when passengers arrive at the baggage claim is greater when walking distances are longer, so there may be fewer people waiting for luggage at any one time at the second airport. Any perceived crowding may further encourage complaints. If all passengers from one of the larger flights are waiting, there may be approximately 145 people in the claim area, with a net floor area available of approximately 14 ft^2/person (2,500 ft^2 less the 490-ft^2 area occupied by the device), which appears more than adequate. The 78.5-ft perimeter of the claim device represents 1.8 ft of display per passenger, again a seemingly adequate amount of space. It would then appear that new baggage claim equipment is not required.

RESEARCH NEEDS

Additional data are needed on characteristics of bags, passengers, and equipment, as well as on airline and airport procedures. Because of the importance of the baggage claim to the passenger's overall perception of an airport and an airline, research into what levels of delay passengers may tolerate and under what conditions is also needed. These data would be valuable as well in mathematical modeling of baggage handling operations, a necessary tool for exploring consequences of new larger aircraft and changes in flight schedules.

NOTES

1. In a survey conducted at Birmingham International Airport in England, it was found that passengers were willing to accept delays in waiting for luggage of as much as 22.5 min before terming service bad. Wait times in the range of 12.5 to 22.5 min were generally found to be tolerable *(1)*.
2. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

REFERENCES

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4. Ralph M. Parsons Co. *The Apron and Terminal Building Planning Report.* Report FAA-RD-75-191. Federal Aviation Administration, U.S. Department of Transportation, July 1975.
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15
Customs and Immigration

Passengers arriving on international flights must generally undergo customs and immigration formalities at the airport of their initial landing in the United States. Federal Inspection Services (FIS) conducts these formalities, which include passport inspection, inspection of baggage and collection of duties on certain imported items, and sometimes inspection for agricultural materials, illegal drugs, or other restricted items.

In recent years, introduction of streamlined procedures for returning U.S. citizens, the "red channel, green channel" system for passing through customs[1], and computerized access to records at inspection stations have substantially speeded the flow of passengers at many airports. Flights from some Canadian and Caribbean airports are precleared at the originating airport, so arrival formalities are substantially reduced or eliminated. Nevertheless, the simultaneous arrival of several fully loaded widebody aircraft can bring a surge of demand that causes service levels to drop dramatically in the international arrivals area.

DESCRIPTION

International passengers generally arrive in an area segregated from other parts of the airport. All passengers must leave the aircraft and proceed through customs and immigration at a flight's first arrival in the United States. There is little layover or transfer activity in international areas of U.S. airports. U.S. citizens currently proceed directly to baggage claim and then to customs, whereas foreign nationals must first clear immigration.

On arrival at one of the several inspection booths, foreign passengers present their passports and other documents and parallel queues form. In some busy airports, roving immigration officers examine documents of passengers in queues, helping to ensure that all documents are in order and thereby reducing the average time required for each passenger to clear immigration.

At most U.S. airports, U.S. citizens' immigration and customs inspections are combined. Following reentry to the United States, U.S. passengers retrieve their baggage and proceed to customs inspection. Conditions at the baggage claim may become a capacity problem when too many people are crowded into the baggage claim area and baggage arrives slowly.

On the basis of declarations made by the arriving passenger and the judgment of the customs inspector, passengers may be required to open their luggage for inspection and may have to pay duties on imported goods. Most passengers proceed directly through an inspection station and exit to the arrivals lobby. The time spent waiting for and undergoing immigration and customs inspections and the conditions of crowding in which the passenger waits determine the service level and capacity of the FIS facility.

Although some airlines have full inspection facilities within their unit terminal areas, these facilities are always under the management of FIS officers. Airlines work with the FIS to ensure that flight arrival schedules are known and that an adequate number of inspectors is available to handle arriving passenger loads. However, variations in airline arrival schedules, government operating standards, and budget constraints may sometimes cause staffing shortages or excessive demand loads. Consequent passenger delays may affect the passengers' opinions of airline and airport operating efficiencies.

The demand and operating factors influencing service level and capacity of customs and immigration are given in Table 15-1. Capacity is generally determined over the short run—typically a peak period of 1 to 2 hr during which several flights may arrive.

DEMAND PATTERNS

Flight arrival schedules are a major determinant of demand at the FIS facilities. Traffic loads are thus frequently influenced by the location of an airport and the consequent predominant points of origin of arriving flights. Airports on the East Coast of the United States often have daily peak load periods in mid-afternoon and late afternoon, when flights from Europe arrive. West Coast airports with significant numbers of Asian flights may have a mid-morning peak.

TABLE 15-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY OF CUSTOMS AND IMMIGRATION

Factor	Description
Number of channels, space, and personnel	Inspector channels, U.S. citizen pass-through positions in immigration, "red-green" channel use in customs
Inspector	Average processing time per passenger, efficiency rate of selection for close inspection policy
Passenger characteristics	Fraction U.S. citizens, flight origin, citizenship of foreign nationals, baggage loads
Space and configuration	Available queue space, access to and configuration of baggage display devices, use of carts
Flight schedule load	Basic determinant of number of people arriving at FIS areas

Flight origins may also influence the degree of attention that arriving passengers receive from FIS inspectors. Flights from some parts of the world may receive careful examination because of concern for drug smuggling or may have large numbers of passengers whose visas and other entry papers are carefully examined. Flights from some countries carry large baggage loads, which places an extra burden on customs inspectors.

The number, size, and load factor of arriving aircraft can be used to estimate passenger loads at customs and immigration facilities. Walking speeds and distances from arrival gates to the inspection areas determine the distribution of actual passenger arrivals.

OPERATING CHARACTERISTICS

Operating procedures and planning standards for customs and immigration facilities are specified by the FIS. However, growth in international travel has made it difficult to maintain planning standards at many airports.

Very little information on actual performance of FIS facilities has been assembled, and the average processing rate of 50 passengers per hour per agent suggested by FAA guidance material *(1)* is cited in many publications. However, it has been observed at New York City's John F. Kennedy International that average inspection rates can increase when conditions are crowded and passenger characteristics permit FIS officers to maintain inspection standards.

Queues may grow very long at some airports. During peak periods at John F. Kennedy International, which is by far the most frequently used point of arrival in the United States, foreign nationals may sometimes have to wait

20 min or more to clear immigration at the International Arrivals Building. The Port Authority of New York and New Jersey is now planning major expansion of these facilities.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

The wait for immigration and customs inspections and the crowding to which passengers may be subjected during these waits are the bases for determining service levels and capacity. A peak period of 1 to 1½ hr is usually appropriate to observe the impact of multiple flight arrivals at most international airports.

The FIS system is reasonably well represented by mathematical multichannel queueing models, and general-purpose simulation procedures may be applied with relative ease. However, for most purposes direct observation of conditions and simple calculations of average delays and queue sizes are adequate for capacity assessment.

Space requirements for waiting passengers are similar to those for other passenger waiting and circulation areas (Chapters 7, 9, 10, and 14). Canadian standards for areas of preclearance to the United States, for example, are similar to those for other departure lounges *(2)*. Those standards define as a breakdown condition space availability less than 0.6 m^2/person (6.5 ft^2/person) for more than 15 min during the peak hour. Space availability of more than 1.2 m^2/person (12.9 ft^2/person) is considered a high level of service and comfort.

Allowance should be made for the passenger's load of carry-on luggage at both immigration and customs stations and for the total baggage load at customs. Many airports provide carts for passengers to use in bringing their luggage to the customs inspection station. At John F. Kennedy International, for example, a planning assumption of 6.25 ft^2 per cart—used by a group of two to four passengers—is being used for sizing expansion of the International Arrivals Building (Port Authority of New York and New Jersey, 1985).

EXAMPLE OF ASSESSMENT PROCESS[2]

Suppose that a small international airport currently serves four international flight turnarounds per day, two of which use Boeing 747 aircraft. Flight arrivals are spaced so that no two flights arrive within 2 hr of each other. A new airline wishes to enter the market and intends to schedule its L-1011 aircraft to arrive at almost the same time as one of the Boeing 747 flights already operating. The airport operator is concerned that facilities are not adequate to handle the new passenger load.

Describe Component

The customs and immigration area is equipped with eight customs inspector positions. There are 12 immigration booths, and the hall in between immigration and customs has approximately 2,800 ft^2 for passengers to wait for luggage or queue for customs inspection.

Describe Demand and Operating Factors

If fully loaded 747 and L-1011 aircraft land at approximately the same time, 550 to 800 passengers may all enter the immigration area within a short period. Average load factors on the existing flights have been 60 to 75 percent.

FIS personnel are available to man all positions if necessary. Queues form at both immigration and customs stations, but there has never been a case in which more than 1 hr was required between flight arrival and clearance of the last passenger. Queues at immigration are seldom longer than six passengers per inspector.

Estimate Service Levels and Service Volumes

Typical standards for customs inspection indicate that inspection rates of 50 to 70 passengers per hour per inspector can be achieved on a regular basis if both flights arrive from countries unlikely to require special scrutiny. Maximum throughput is estimated as follows:

$$\begin{aligned}\text{Customs throughput} &= (\text{inspectors}) \times (\text{inspection rate})\\ &= (8) \times (50 \text{ to } 70 \text{ passengers per hour})\\ &= 400 \text{ to } 560 \text{ passengers per hour}\end{aligned}$$

Time required to clear both flights would then be 50 to 65 min, assuming normal (60 to 75 percent) load factors. Fully loaded aircraft would require 80 to 90 min. Although these times are a significant increase over the existing situation, they may be acceptable to the airlines.

However, it may be expected that at least one-third to one-half of the passenger load may be waiting for baggage or queued at a customs station at

one time. In that case, even with typically loaded aircraft, there could be as many as 400 waiting in the 2,800 ft² of space in the hall. At 7 ft² per person, conditions could approach serious crowding.

RESEARCH NEEDS

The FIS generally tries to maintain high service levels in customs and immigration but may be limited by the availability of inspectors. In such cases the airport operator is requested to provide additional space for waiting passengers and to somehow lessen the annoyance of these passengers as waits grow long. Additional research on willingness to tolerate delay and how this willingness might be improved by terminal design and operations measures would prove useful. Continuing efforts to streamline arrival procedures and to improve speed and accuracy in customs screening may relieve problems at airports experiencing rapid growth in international traffic.

NOTES

1. This system, long popular in European ports of entry, permits arriving passengers with no goods to declare to proceed without stopping through the "green channel" corridor of customs. The baggage of all those passengers using the "red channel" and of randomly selected passengers in the "green channel" is scrutinized by customs inspectors.
2. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

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16
Connecting Passenger Transfer

An airport's ability to accommodate the quick and efficient transfer of connecting passengers and their baggage from an arriving aircraft to a subsequently scheduled aircraft departure is important to passenger safety, comfort, and convenience, as well as to airline operating efficiency. Airports serving significant numbers of connecting passengers increasingly play a key role in the nation's air transportation system.

DESCRIPTION

Transfer passengers must travel with their carry-on baggage from one gate to another by walking or with the aid of buses or other mechanical devices, sometimes moving between separate terminal buildings, possibly leaving and reentering secure areas, and sometimes using check-in and other facilities along the way. Arriving international passengers must pass through customs and immigration and claim and recheck their luggage.

When an on-line connection is made (between two flights operated by the same airline), the airline will typically try to ensure that the passenger is assisted with the transfer. Airline hub-and-spoke operations depend on the ability of passengers to make the transfer quickly and easily. Transfer passengers arriving and departing on flights operated by different airlines must make an interline transfer. Typical problems encountered by transfer passengers making transfers at some airports include long distances to be traversed, obstacles such as changes in elevation and unprotected areas separating terminals, and poor information on where the next flight's gate is located.

TABLE 16-1 DEMAND AND OPERATING FACTORS INFLUENCING SERVICE LEVEL AND CAPACITY FOR PASSENGER TRANSFER

Factor	Description
Terminal configuration	Distance between gates, information for connecting passengers, intervening security screening
Ground transport	Connecting passenger assistance systems, baggage transfer systems
Passenger characteristics	Fraction needing assistance for ground transport, intergate travel speeds, baggage loads
Flight schedule and load factors	Basic determinant of number of people making peak-period connections

Standard minimum connection times listed in the Official Airline Guide (OAG) and agreed on by airlines and reported to the travel industry are generally based on access time for passengers and 100 percent transfer of baggage. In this chapter the focus is on passenger transfer, and it is assumed that the baggage transfer times agreed on by the airlines are adequate.

The principal demand and operating factors influencing service level and capacity for passenger transfers are given in Table 16-1. These factors influence how long it may take for passengers to make the transfer, which is the primary basis for judging service level and estimating capacity.

DEMAND PATTERNS

Transfer passenger traffic in general varies with the number of flight arrivals and departures scheduled within a period of 60 to 120 min. On-line connecting passengers usually have a short journey for their transfer. However, rapid growth in activity at airports where airline hub-and-spoke operations are centered has sometimes led to widely separated on-line gates and subsequently longer connection times.

If an airline operates a route hub at a particular airport, the number of interline passengers will be reduced, although total transfer traffic may be high. Large airlines have in recent years formed associations with small commuter carriers in which flight times of the major carrier's long-distance flights are coordinated with those of the commuter carrier, so that the latter serves as the feeder to the hub. Often the two carriers share terminals and gate space, making transfers easier for passengers on those particular airlines.

At some large airports, the passengers of interest should also include originating and terminating passengers who may have an automobile parked near the terminal of an airline other than the one on which they are currently traveling and who then use the airport's interline transfer system to reach their vehicle. Some analysts have observed that the number of these "phantom transfers" may become relatively significant *(1)*.

OPERATING CHARACTERISTICS

The physical design of the airport's terminal facilities is the principal variable influencing service provided to transfer passengers. However, effective signing and other assistance to aid the transfer passenger may influence their ability and perceptions of service offered and mitigate some difficult aspects of making a transfer.

In many airports, interline transfer passengers have no choice but to walk from one airline's area to another's. But in some large airports, systems are available to aid the passenger in this movement, such as moving walkways, people movers, and interterminal buses. Buses, however, are subject to congestion on airport roadways and at the terminal curb. Collection of fares for buses and people movers makes these facilities less effective and desirable from the passenger's point of view.

The time that passengers require for transfer will depend on the characteristics of the passengers as well as the design of the airport. Some airports in Florida, for example, have a high proportion of elderly passengers who may require longer times to traverse a given distance. People movers, moving sidewalks, and buses may improve transfer times in such airports.

Large hub airports[1] typically require a longer time for transfer passengers than do small hub airports. For example, in the OAG, which lists standard minimum connection times for major airports in the United States, the average time required for interline transfers at large hub airports (approximately 45 min for domestic and 75 min for international connections) is nearly twice that for small hub airports *(2)*. These statistics are summarized in Figure 16-1 and Table 16-2.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

There are virtually no analytical techniques intended to deal specifically with passenger transfers. Assessment of this component of the landside typically requires a direct estimation of transfer times by using assumptions about passenger walking speeds, measured distances at the airport, and obstacles or aids to movement. At some airports, the assessment may be appropriately

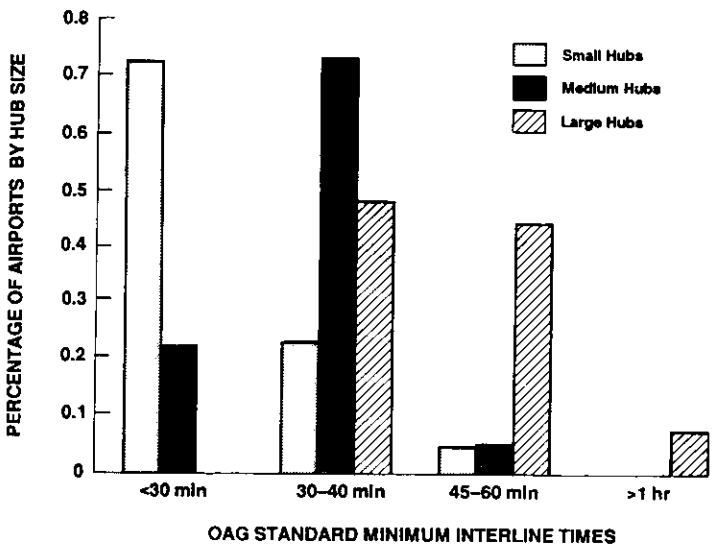

FIGURE 16-1 Distribution of minimum standard interline connection times at 112 primary U.S. airports by hub size *(2, 3)*.

TABLE 16-2 AVERAGE MINIMUM ALLOWABLE INTERLINE CONNECTION TIMES AT U.S. AIRPORTS *(2, 3)*

Airport Type and Flight	Avg Minimum Interline Connection Times (hr:min)	
	Domestic	International
Hub		
Large	0:45	1:16
Medium	0:30	1:02
Small	0:23	0:47
Flight		
Long haul	0:39	1:10
Medium haul	1:35	1:08
Short haul	0:20	0:10

conducted in conjunction with the assessment of access or general circulation conditions.

EXAMPLE OF ASSESSMENT PROCESS[2]

Suppose that a large hub airport has several separate unit terminals linked by a bus traveling on the frontage road (Figure 16-2). The OAG recommends a minimum interline transfer time of 40 min. Interline transfer passengers may walk between terminals or wait for the bus. The airlines and airport have received numerous complaints about delays and difficulty in transferring between terminals.

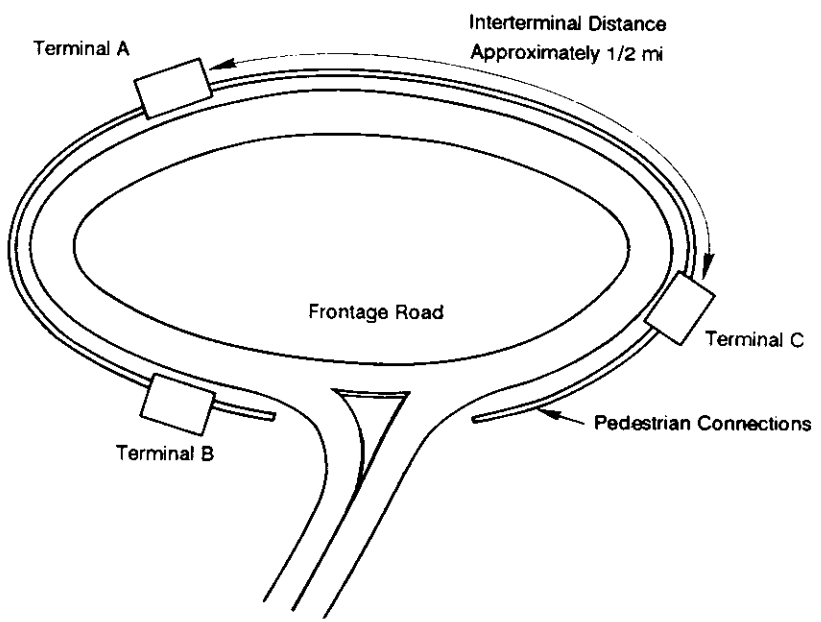

FIGURE 16-2 Example of assessment for interline transfers (drawing not to scale).

Describe Component

The three terminals are separated by approximately 1/2 mi. Buses circulate at 5-min intervals, with an average time between stops of approximately 2 min, although frequent traffic congestion may slow circulation substantially.

Describe Demand and Operating Factors

Airport management has observed that deplaning transfer passengers with baggage generally reach the curbside bus stops within 14 to 22 min of their arrival. Without baggage, passengers reach this point within 4 to 6 min. Passengers then choose either to wait for a bus or to walk to the terminal where their departing flight is located.

Approximately 30 percent of interline transfer passengers have little hand-carried luggage and could walk to the terminal if necessary. Approximately 50 percent of those choosing the bus must go to the second terminal away from their current position before reaching their destinations.

Bus operations are as described in the previous paragraph. Passengers choosing to walk may travel through covered corridors, although there are some stairs or ramps to be negotiated. Walking routes are well signed.

Estimate Service Levels and Service Volumes

Under uncongested conditions, transfer passengers using the bus to travel to the most distant terminal wait approximately 2 to 3 min for a bus to arrive and then ride for 4 min. Total time to reach the curb of the second terminal is then approximately 20 to 29 min. Allowing 7 to 10 min for check-in and walking to the gate, the total time required for these passengers is 27 to 39 min. At the upper end of this range, the service level is close to the OAG standard of 40 min minimum connecting time, but there is little safety margin for time lost to traffic congestion along the terminal curb.

A transfer passenger choosing to walk may go directly to either terminal. Such a passenger travels at an average speed of perhaps 180 to 250 ft/min. The 1/2 mi between terminals is traveled in approximately 21 to 30 min. This passenger then arrives at the second terminal within 25 to 36 min. Again allowing 7 to 10 min at check-in, the total time is 32 to 46 min. At the upper end of this range, the 40-min target is clearly not met.

On the basis of this analysis, the airport operator may conclude that there is too little safety margin for slow traffic. A more detailed study of the problem may be warranted to investigate whether improvements in service levels are needed.

RESEARCH NEEDS

Data on length of time and maximum walking distances for interline transfer that passengers will tolerate would be useful for assessing service levels and determining capacity to serve connecting passengers.

NOTES

1. As defined by FAA; see the glossary.
2. Subsections correspond to Steps 3, 5, 7, and 8 in the assessment process shown in Figure 3-1. Attention may also be given to relevant relationships among components (Step 4) and community factors (Step 6).

REFERENCES

1. R. deNeufville. *Airport Systems Planning*. Macmillan Press, London, 1976.
2. *Official Airline Guide, North American Edition*, Vol. 12, May 1, 1986.
3. *National Plan of Integrated Airport Systems* 1984-1993. Federal Aviation Administration, U.S. Department of Transportation, 1985.

17
Landside System as a Whole

The components discussed in the preceding chapters are linked together in an airport terminal into a total system through which passengers move to and from aircraft. Small queues and short delays in each component, although individually well within tolerable ranges of performance, may still combine to produce a landside capacity problem. The capacity of the landside system of a particular airport taken as a whole is more difficult to assess than that of an individual component, but nevertheless it can be done. However, there is no single service level or capacity for the whole system in the same sense as there is for a single component unless demand on all components is perfectly matched to each component's maximum throughput or there is an accepted set of comparable service-level targets for all components and all components are operating at these target service levels.

Discussions of the terminal system as a whole consider total processing time for the enplaning and deplaning passenger. This total processing time is a sum of three elements—the service time at each component, the wait time at each component, and the travel time between components that make up the system. There are no generally accepted standards for this total processing time, although an individual airport may set its own maximum acceptable standards and compare actual performance with these.

DESCRIPTION

Individual components are linked together in parallel and in series, defining the paths passengers may take through the system. Figure 17-1 shows an example of these linkages.

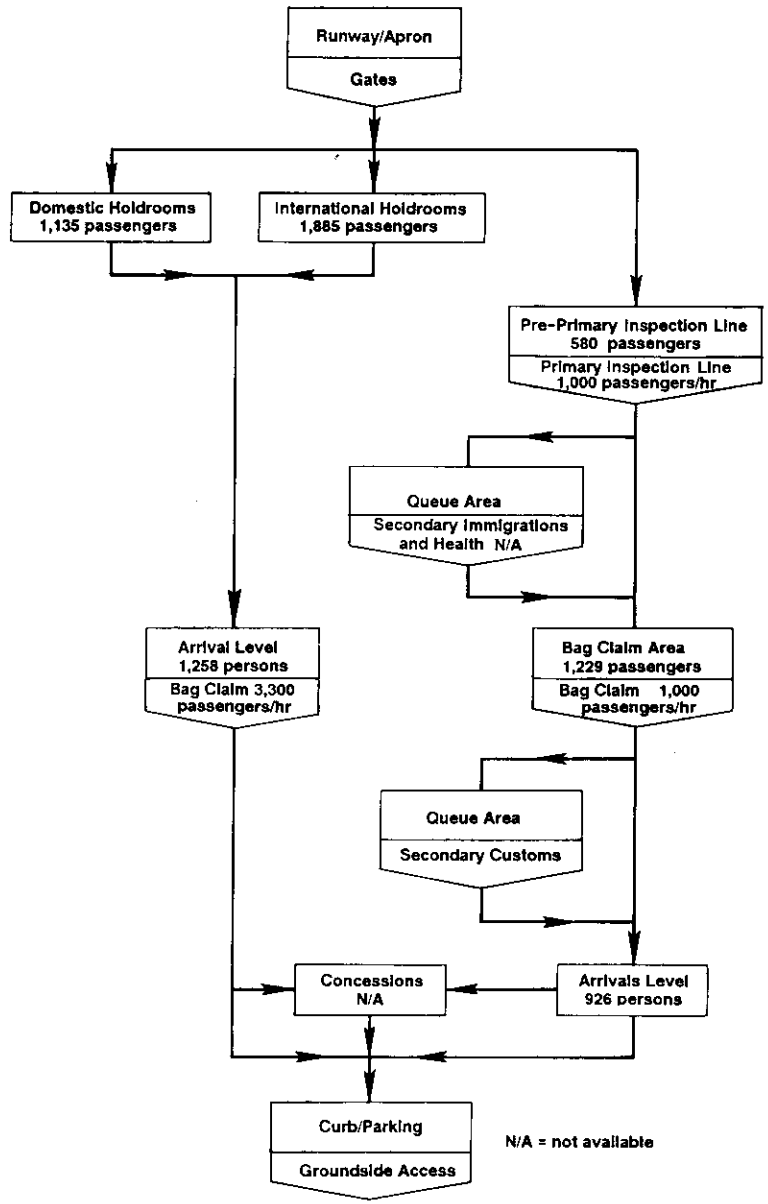

FIGURE 17-1 Example terminal landside flow schematic (deplaning) *(1)*. Terminology corresponds to Transport Canada practices. Primary inspection line corresponds approximately to FIS activity in U.S. airports.

If all components are operating at their maximum throughput rates, throughput of the terminal as a whole is determined by the most constrained component in each independent parallel path. In theory, although service levels for these most constrained components may severely deteriorate, the system as a whole will still be able to continue processing passengers. In practice, serious crowding and congestion in one component often affect demand in connecting components and service levels decline overall.

In general terms, all the factors previously discussed as influencing the levels of service and capacity of individual components influence the landside system as a whole. The number of passengers that can be served by the whole system is limited by the conditions that can be tolerated in individual components. The achievable service volume of an airport's landside as a whole is the level of aggregate demand that places loads on an individual component that in turn cause service conditions to drop to a minimum acceptable service level.

In an airport where all passengers use the same facilities, this limit may be highly visible and may restrict the airport's operations. Capacity assessment for smaller airports and airports served by a limited range of access facilities may for this reason be particularly meaningful. In more complex landside systems severe problems may develop in one part of the airport; for example, one of several unit terminals may perform at very low levels of service. Greater numbers of people could be served at this airport if these new passengers used the less severely stressed terminals. However, given current patterns of demand, operating procedures, and facilities configurations, it may be entirely reasonable to say that the airport has reached a limiting service volume.

Although total time required to traverse the landside system is a frequently discussed measure of overall service level, other measures may be used. For example, the risk that a passenger will miss his flight's scheduled departure can be estimated if there are adequate data. Whatever the measure, all components may individually perform with acceptable service levels, yet cumulative effects may cause the landside system as a whole to be judged unable to satisfy demand.

DEMAND PATTERNS

Both timing and distribution of demand among components are important. For an obvious example, two aircraft can occupy the same gate at different times but will need two gates if they are to be served at the same time. Passengers arriving on these aircraft may encounter serious delays in baggage claim if they all arrive at one time and no delay at all if they arrive at different times. They may also encounter no delays at baggage claim if a large fraction of the passengers are transferring between flights.

The passenger demand associated with the full day's flight schedule must generally be considered, both by time of day and by where these aircraft are parked. Passengers entering the landside—deplaning through gates in a system such as that shown in Figure 17-1 or enplaning via access roads and the terminal curb—make their way from one component to the next and in doing so influence service conditions along the way. The likely rate at which this movement occurs may be estimated from the flight schedule and estimated characteristics such as walking speed and walking distance. Alternatively, periodic observations of service time, occupancy level, queue length, and other indicators of service level may be made and linked by inference to flight schedules and passenger characteristics. Standardized relationships may then be developed for a particular airport or part of an airport (Table 17-1) and used in capacity assessment and planning, although these relationships are necessarily only an approximation of actual conditions.

OPERATING CHARACTERISTICS

It is difficult—if not impractical—to discuss operations of the landside as a whole without reference to individual components. Shifting demand among components to achieve a balance in service conditions is the principal means for achieving optimum passenger service volumes. In an ideally balanced landside system, demand is matched to component capacities so that all component service levels are comparable. (This presumes that comparable definitions of service levels can be developed for many diverse components.) The landside system as a whole can then be said to operate at a service level similar to that of each component. If service-level targets can be established for critical components at a particular airport, system service level may be termed adequate if all components are operating at or above their target and if overall processing time is also considered adequate.

ANALYSIS TOOLS AND ASSESSMENT STANDARDS

There are at present no generally accepted standards of overall landside system performance. The relative consistency of passenger behavior in arriving at an airport in advance of scheduled departure demonstrates that such standards may be developed but data are at present not adequate.

Landside systems of even moderate complexity cannot be effectively assessed without some type of simulation, and computer assistance is often

TABLE 17-1 TYPICAL PASSENGER DEMAND DISTRIBUTION: TERMINATING FLIGHTS, VANCOUVER INTERNATIONAL *(1)*

Component	Maximum Percentage of Flight Load in the Area	Time After Arrival of Aircraft (min)
Customs baggage		
Transborder	52	15
International	42	30
Domestic baggage		
Short haul	56	8
Long haul	62	10
Main arrival-level concourse		
Short-haul domestic	30	15
Long-haul domestic	32	14
Main departure-level concourse		
Short-haul domestic	8	12
Long-haul domestic	4	10
Transborder	8	25
International	14	100
International arrival-level concourse		
Transborder	26	22
International	34	55
Terminal total		
Short-haul domestic	98	4
Long-haul domestic	100	4
Transborder	100	4
International	100	8

needed. A number of attempts have been made, with mixed success, to devise detailed and generally applicable computer-based simulations of the terminal landside as a whole, at least for the terminal building and gate complex (see Appendix B).

Analytic procedures include the critical path method (CPM), probabilistic queueing and network modeling, and "brute force" (in which the computer goes through many iterations of applying demand and estimating service levels in the abstract system model of the airport). In each case the analysis results are presumed to represent likely conditions in the real airport.

Assessments of individual components yield estimates of service volumes and service levels achievable over some period of time under known or assumed demand characteristics. These individual component service volumes converted to equivalent hourly volumes may be used to represent the system. When demand is not balanced to capacity throughout the system (e.g., when service level falls below target in one or more individual components), an approximation of achievable system service volume may be estimated by calculating the ratio of the below-target component's maximum service volume to that component's share of total system demand served. The component yielding the lowest computed equivalent system volume then determines the approximate limit of overall landside service volume.

EXAMPLE OF ASSESSMENT PROCESS[1]

Suppose that an airport has two identical unit terminals. Assume that the entire assessment process has been completed for each terminal and that the airport operator wants an estimate for planning purposes of total airport service volume achievable with current facilities.

Describe Component

Assume also, for simplicity, that the peak-hour service volume for each terminal was found in the preceding assessment to be limited by gate occupancy, although proposed introduction of widebody aircraft could overload existing ticket counter and baggage claim facilities.

Describe Demand and Operating Factors

Flight schedules have been analyzed and counts have been made of passenger movements through the terminals. Both terminals have 10 gates, all in use during their peak hours. The peak total number of passengers passing through either terminal during the respective peak hours is approximately 1,500, 60 percent of whom are moving in the peak direction (i.e., either enplaning or deplaning). However, peak hours for Terminal A are in the early morning and late afternoon, whereas those for Terminal B occur at midday. Average total daily passenger counts are 9,000 at Terminal A and 7,500 at Terminal B. The airport's annual traffic is approximately 5 million passengers.

In preceding analyses, the maximum acceptable future peak-hour demand for each terminal was estimated to be 2,000 total passengers in the peak hour, based on assumptions that widebody aircraft are introduced, no new landside facilities are constructed, and 60 percent of peak-hour passengers move in the peak direction. At this demand level, service levels forecast at ticket counter and baggage claim are below what the airlines and airport operator are likely to find acceptable.

Estimate Service Levels and Service Volumes

Apparent maximum service volume for the two terminals together, acting independently and in parallel, would be the sum of their individual maximum volumes, or 4,000 total passengers per hour. This estimate presumes that ground access and parking facilities, on the one hand, and airside facilities, on the other hand, can accommodate the combined peak-hour operations. Over the course of the 16-hr service day, traffic volumes could be as high as 64,000 total passengers per day.

However, if patterns of demand are maintained, Terminal A will continue to serve nearly 55 percent of the airport's daily traffic. As the airport's total traffic grows, Terminal A will achieve its maximum service volume before Terminal B, and can serve daily traffic of approximately 12,000 total passengers. In the absence of changes in patterns of demand, daily traffic at the airport would then be approximately 22,000 passengers, which is probably a more realistic estimate of the terminal area's maximum achievable service volume with existing facilities.

RESEARCH NEEDS

Measures of total landside system performance are extremely valuable. Although data are collected on airside delay due to a variety of causes, comparable data are seldom collected for the landside. Such landside data would not only support development of service-level targets at individual airports but would also assist airport operators and the FAA in discussions of appropriate balancing of investments in airside and landside facilities to achieve optimum airport system operations.

NOTE

1. The subsections of this example correspond generally to Steps 3-8 in the assessment process described in Part 1. However, analysis of the landside system as a whole generally must be preceded by or include assessments of individual components. System analysis is accomplished by using these previous results and is concentrated in the interactive accomplishment of Steps 7-9 in the general process.

REFERENCE

1. *Air Terminal Processing Capacity Evaluation*. Report TP5120E. Airport Services Branch, Transport Canada, Ottawa, Ontario, Jan. 1984.

Glossary

Included here are definitions of selected terms helpful to understanding and discussing airport landside capacity. Terms in italics are defined elsewhere in the glossary.

ACCESS. In the context of aviation activities, the airlines' ability to offer service at new airport locations or to increase service at airports already served (see *Ground access*).

AIR TRAFFIC CONTROL (ATC). The federally regulated system of rules, procedures, instruments, and personnel intended primarily to assure flight safety. ATC procedures may have substantial influence on timing of aircraft departures and arrivals at an airport.

AIRCRAFT OPERATION. Aircraft departure from or arrival at an airport; takeoffs and landings. Airside facilities must serve all operations (including those of general aviation), whereas landside activity is typically related only to departures or arrivals of *commercial service* aircraft.

AIRPORT COMMUNITY. In broad terms, those served by an airport. This includes passengers, shippers, and other airport *users*; employees of the airport and businesses relying on air transportation; neighbors of the airport, especially those exposed to aircraft noise, airport access traffic congestion, noise, and pollution; and local and state government.

AIRSIDE. Airport facilities associated with aircraft movement to transport passengers and cargo, used primarily for landing and take-off, for example, runways, taxiways, and ATC facilities. The airside may overlap the *airspace* at ends of runways.

AIRSIDE CAPACITY. See *Capacity (airside)*.

AIRSPACE. Designated area beyond the airport where aircraft are permitted to operate, often under ATC regulations; may overlap the *airside*.

ANALYSIS PERIOD. Specified period of time, typically a peak period, used for analysis of landside capacity. Choice of period depends on *functional components* considered and *demand characteristics*.

APRON. Aircraft interface between *landside* and *airside*. It includes ramps and aircraft circulation area.

AUTOMATED GUIDEWAY TRANSIT (AGT). Fixed-guideway system for transporting passengers between central *terminal* and *remote terminal*, among unit terminals, or to other airport facilities.

BAGGAGE SERVICES. Processing of passengers' checked baggage. Included are destination tagging, movement to baggage room, sorting, movement to and from aircraft, loading and unloading, and delivery to baggage claim display device. *Interline transfer*, storage, and delivery may be included.

CAPACITY (AIRSIDE). As defined by the FAA, the maximum number of aircraft operations that can take place in an hour. This is a *maximum throughput* rate.

CAPACITY (LANDSIDE). As defined in this study, capability of the *landside* or its *functional components* to accommodate passengers, cargo, ground transport vehicles, and aircraft. *Service volume* is the principal indicator of landside capacity in this report.

CHECK-IN. Initial step in passenger processing, involving passenger contact with the airline immediately before flight departure. It may include ticket inspection, issuance of boarding pass and seat assignment, baggage checking, ticketing, and preliminary inspection of immigration documents and may occur at ticket counter or gate area. To speed processing, some steps may be completed in advance of passenger arrival at the airport.

CLEAR ZONE. Area at ends of runways and other areas surrounding airport in which height and land use limitations are imposed to ensure that no obstructions to safe aircraft operations occur.

COMMERCIAL SERVICE AIRPORT. As defined by the FAA, public use airport receiving scheduled passenger air service and enplaning at least 2,500 passengers annually. There are 552 such airports included in the FAA's 1984 National Plan of Integrated Airport Systems (NPIAS).

COMMUTER. Airline providing service primarily over *short-haul* route segments connecting small airports to *hub* locations. The term also refers to the smaller aircraft used for such services, typically with seating for 10 to 50, and to the general service conditions associated with such airline operations.

CONNECTING PASSENGER. A *transfer* passenger.

CROWDING. Density of people in airport waiting areas, or number of people per unit area. Those accompanying departing passengers or greeting arrivals may be included as well as passengers themselves.

DELAY. For the airside, added time spent in accomplishing an aircraft operation because of airport congestion, or the difference between time required under constrained conditions caused by simultaneous demands on the facility and time required under unconstrained conditions. Landside delay is the added time required for a passenger to complete processing at a *functional component* because of limits to capacity. Wait time and processing time are included. Acceptable delay depends on type of service being delivered, *demand characteristics*, and local conditions at an airport.

DEMAND CHARACTERISTIC. Number of air passengers and aspect of their behavior that materially affect the ability of a *functional component* or group of components to accommodate them. Such factors as the timing of passenger arrivals at the airport, age, trip purpose, fare paid, baggage carried or checked, and whether passenger has a ticket and boarding pass are often important. Airlines often try to tailor their services to their passengers' demand characteristics.

FEDERAL INSPECTION SERVICES (FIS). Federal government processing of international passengers and baggage, primarily on arrival in the United States. Immigration, customs, agricultural, public health, and narcotics control functions are included. Terminal areas for international arrivals include FIS facilities staffed and operated by federal employees.

FUNCTIONAL COMPONENT. Element of the landside such as a gate or ticket counter that provides specific service to air passengers or cargo. Functional components unable to meet demand characteristics and maintain adequate service levels may become limits to capacity.

GATE. Terminal portal for passengers to enter and exit aircraft. The term is commonly used to mean a *loading bridge*-equipped entry adjacent to a *holdroom*, but may include entry to a *transporter* or directly onto an *apron*. It sometimes includes the *hardstand*.

GENERAL AVIATION. Activities associated with private and business aircraft as opposed to common-carrier passenger aircraft and airports with less than 2,500 annual enplaned passengers or used exclusively for such activities. In addition to *reliever airports*, 2,440 general aviation airports are included in the NPIAS.

GROUND ACCESS. Highways, local streets, fixed guideway systems, and public and privately operated transit services linking an airport to the area that it serves.

GROUND HANDLING. Unloading and loading of catering supplies, baggage, and cargo; fueling; and minor maintenance on the *apron* associated with servicing an arriving aircraft and preparing it for departure.

HARDSTAND. Aircraft apron parking position equipped with fixed facilities for *ground handling* but not directly linked to a terminal. It may be considered as a *gate*.

HOLDROOM. Passenger waiting area adjacent to *gate*. The term is also used to refer to other passenger waiting areas such as that for immigration or baggage claim devices.

HUB-AND-SPOKE OPERATION. A pattern of airline routes that brings direct flights from many points (the spokes) to a centrally located airport (the hub). Flight schedules allow passengers to transfer quickly between flights during periods when many aircraft are simultaneously at the hub location. Such a route structure is intended to maintain high levels of aircraft utilization and loading. Airline hubs increase proportions of passenger transfer traffic. These transfer centers do not necessarily qualify as *hub airports* as defined by FAA.

HUB AIRPORT. A standard metropolitan statistical area (SMSA) and the *commercial service airports* serving that area that account for at least 0.05 percent of all passengers enplaned annually in the United States. Because some SMSAs are served by more than one airport, there are fewer hubs than there are hub airports. Hub airports are classified by the percent of total domestic enplanements as large (1 percent and more), medium (0.25 to 0.99 percent), and small (0.05 to 0.25 percent). The NPIAS includes 140 hub airports.

INTERLINE TRANSFER. A passenger and his checked baggage changing from one air carrier to another while in transit at an airport. Such transfers, in contrast to transfers within the same airline *hub-and-spoke operation*, pose particular problems of baggage-handling logistics and may require passengers and baggage to move between terminal buildings at larger airports.

LANDSIDE. Facilities and services associated with air passengers or cargo movement between aircraft and trip origin or destination. The landside includes *aprons, gates, terminals*, cargo storage areas, parking, and *ground access*.

LANDSIDE CAPACITY. See *Capacity (landside)*.

LOADING BRIDGE. Mechanical device and passenger pedestrian pathway to link *terminal* to aircraft. Sometimes called a "jetway," although this term is a registered trademark.

LONG HAUL. Flights longer than 1,500 mi. Such flights normally require more preparatory ground time before departure than *short-haul* flights (those less than 500 mi long) and are often flown by larger aircraft.

MAXIMUM THROUGHPUT. Maximum rate at which passengers (or aircraft, ground transport vehicles, pieces of baggage, tons of cargo, etc.) can be processed by a *functional component* or group of components. In practice this rate is observed only when demand equals or exceeds a component's processing capability, and is typically sustained only for brief periods, because excess demand usually produces significant delays and crowding.

OFF-LINE TRANSFER. Passenger changing planes between flights operated by different airline companies. Also termed *interline transfer*.

ON-LINE TRANSFER. Passenger changing planes between flights operated by the same airline company. Times required for on-line transfer may be shorter than those for off-line transfers because gates are located closer together and flight schedules are coordinated.

PART 150. Portion of Federal Aviation Regulations (FAR) implementing aircraft noise measurement and compatible land use planning to limit areas and population exposed to aircraft noise.

PASSENGER CIRCULATION AREA. Corridor, stairway, escalator, or moving walkway connecting processing components, generally only in a *terminal*.

PASSENGER SCREENING. Security inspection of passengers and hand-carried baggage in preparation for enplanement. Such screening typically includes x-ray and occasional hand search of baggage and metal-detector (magnetometer) examination of passengers.

PEAK LOAD FACTOR. The ratio of demand during the peak period (for example, a peak hour) to average demand during a reference period (for example, the daily average hour). Generally expressed as a number or percentage, for example, 1.2 or 120 percent.

PEAK PERIOD. Time period, which may be one hour, several hours, or one day, representative of busy conditions within a *functional component*. It is typically defined from historical records by frequency of occurrence.

PEOPLE MOVER. A type of *automated guideway transit* (AGT).

PRIMARY AIRPORT. *Commercial service airport* at which at least 0.01 percent of all U.S. passengers are enplaned annually (as reported in the NPIAS, equal in 1982 to about 31,000 enplanements). The NPIAS lists 280 such airports.

RAMP. Aircraft parking position, often used to refer to gate parking positions.

RAMP CHART. A graphical presentation of the daily schedule of flight operations for a group of gates. The chart shows scheduled arrival and departure times, and thus when a gate is occupied.

RELIEVER AIRPORT. General aviation airport that has the designated function of relieving congestion at *primary airports*. Such airports increase access for general aviation to the community and may be candidate locations for airlines wishing to expand service or enter new markets. The NPIAS lists 227 reliever airports.

REMOTE PARKING. Automobile parking areas located at some distance from the *terminal* and connected to it by shuttle bus service or a *people mover*.

REMOTE TERMINAL. Facility located at some distance from an airport where passengers may undergo some part of the processing associated with

the landside portion of the trip. Remote parking and check-in may be included.

SERVICE LEVEL. The quality and conditions of service of a *functional component* or group of components as experienced by passengers. Such factors as delay, crowding, and availability of passenger amenities for comfort and convenience measure service level.

SERVICE-LEVEL TARGET. Minimum or maximum tolerable service level during a particular analysis period established by airport operator, airlines, the FAA, and the community to guide decision making.

SERVICE TIME. Time required, excluding waiting time, to process a passenger at a *functional component* such as a ticket counter or passenger security screening facility.

SERVICE VOLUME. Number of passengers (or aircraft, ground transport vehicles, etc.) with particular *demand characteristics* that can be accommodated by a *functional component* or group of components during an analysis period at a given service level.

SHORT HAUL. Flights less than 500 mi long. Aircraft on short-haul routes may be able to operate with very short *turnaround times* compared with those on *long-haul* routes.

STRUCTURED PARKING. Multilevel building for automobile parking at airport.

TERMINAL. Building with facilities for passenger processing and boarding of aircraft or groups of such buildings (unit terminals, often used by a single airline) within a terminal area. Terminals are often classified into four configurations by the system used for horizontal movement of passengers: linear, pier, satellite, and transporter (see Figure G-1).

TERMINAL CURB. Passenger interface between *ground access* and *terminal*. Passengers arrive or depart in private automobiles, hotel and rental-car vans, limousines and buses, and transit vehicles. The curb system may include direct rapid transit and rail system links to the airport, although stations are typically located elsewhere and linked by bus or pedestrian paths to terminal buildings.

TRANSFER. Passenger changing planes at an airport en route to the final destination. Such passengers, either *on-line* or *off-line transfers*, typically are at the airport for a relatively short period of time and use fewer landside facilities and services than passengers starting or ending their journey at the airport. Airline *hub-and-spoke operations* sharply increase the number of transfers at the *hub airport*.

TRANSPORTER. Mobile vehicle for carrying passengers between *terminal* and *hardstand*.

TURNAROUND TIME. Scheduled time required between aircraft arrival and departure for passenger unloading, *ground handling*, and boarding.

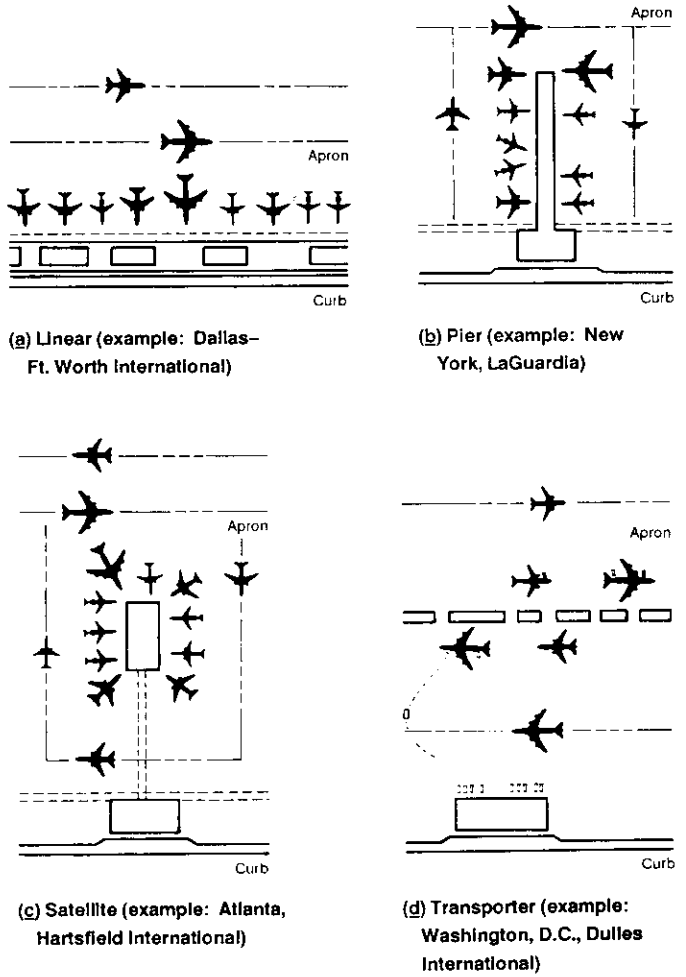

FIGURE G-1 Airport landside terminal configurations.

USER. Broadly understood to include passengers, airlines, cargo shippers, concessionaires, and others who use airport landside facilities and services. In this report, passengers are the principal users, and are served by airlines and airport operations.

WIDEBODY. High-passenger-capacity jet aircraft such as the Airbus, Boeing 747, McDonnell-Douglas DC-10, and Lockheed L-1011. Physical dimensions of such aircraft, also termed jumbo jets, may be incompatible with airport *gate* and *apron* areas designed for smaller narrowbody aircraft.

Appendix A
Framework for Defining Airport Landside Service-Level Targets

There are no generally accepted definitions or targets for acceptable landside service levels at U.S. airports. A comprehensive set of such targets is a logical prerequisite for consistent nationwide assessments of landside capacity. This study was undertaken with the hope of recommending target levels, but the committee concluded that existing data are simply inadequate to support even a suggestion of targets that might be applied nationwide. Nevertheless, a guiding framework for developing landside service-level targets can be recommended and is described briefly here.

The framework has four principal dimensions:

- Type of airport,
- Type of air transport service,
- Prototypical service-level target, and
- Landside functional component.

Other dimensions that may influence selection of service-level targets at a particular airport include geographic location of the airport, its role within a regional and national airport system, and management characteristics such as financing arrangements.

Research is needed to extend the framework proposed here beyond commercial passenger capacity. Cargo services offered by passenger airlines and dedicated air cargo transporters place significant demands on landside facilities at many commercial service airports and should be considered in any determination of airport landside capacity.

TYPE OF AIRPORT

Airport size is a key factor influencing passenger experience. A physically small airport takes less time to negotiate than a large airport and offers a narrower range of passenger amenities. The FAA's classification of commercial service airports into four categories by number of annual passenger enplanements may be a reasonable basis for setting targets *(1)*. For example, there is a strong correlation between this measure of airport type and minimum interline flight connection times accepted by the airlines serving a particular airport.[1] A similar correlation may be found between size and such service-level indicators as baggage claim service time, gate occupancy time, and total time required for passengers to travel through the landside.

Overall layout of the airport terminal area may influence capacity as well. For example, multi-building terminals typically make interline passenger and baggage transfers more difficult than more centralized configurations, but may offer advantages for apron and gate area utilization.

TYPE OF AIR TRANSPORT SERVICE

Whether an airline hub-and-spoke operation is centered at a particular airport is another important factor. The daily pattern of passenger peak loads changes substantially when an airline hub begins operation, particularly with respect to the number of peaks. An airline hub typically increases the number of peaks and raises average daily utilization of gates and holdrooms.

Predominant stage lengths of flights originating at an airport (e.g., long versus short haul) and travel market served typically influence times required for aircraft ground handling, passenger access requirements, passenger baggage loads, and amenities airlines offer their passengers. A significant number of long-haul international flights at an airport, commuter operations, low-fare budget airlines, charter operations, and airlines serving primarily business travel or vacation and tourist destinations each have a particular influence on service-level targets.

PROTOTYPICAL SERVICE-LEVEL TARGET

A generally applicable and easily understood description of service levels is a valuable basis for setting service-level targets at any particular airport. The broad international acceptance of the highway level-of-service descriptions on a scale of A through F, from "free flow" to "breakdown," presented in TRB's *Highway Capacity Manual* demonstrates the point.

Although proposals have been made to adapt the six highway level-of-service prototypes to the airport landside *(2)*, the committee believes that such a scale may be overly detailed and proposes three prototype service levels:

- Level 1: Passengers are unlikely to encounter delays, queues, or crowding. Aircraft operations are not affected by landside conditions.
- Level 2: Passengers may encounter some delay at isolated locations or for limited times during peak periods. Some queueing and crowding are observed. Aircraft operations are not affected by landside conditions.
- Level 3: Passenger delays are likely. Queues and crowding are observed generally throughout peak periods. Aircraft operations may be affected by landside conditions.

These prototypical service levels are based on the committee's experience with conditions typically encountered at U.S. commercial service airports. Research is needed to determine specific criteria for likelihood of occurrence of delays, queues, and crowding, and their effect on aircraft operations.

LANDSIDE FUNCTIONAL COMPONENT

A comprehensive set of service-level standards should address each of the 11 individual types of functional components and the landside system as a whole, as discussed in Part II of this report. Unique conditions at some airports may justify establishing service-level targets for other landside components as well, for example, to monitor interairport connecting time in a multiairport region.

NOTE

1. This relationship is discussed with respect to assessment of Connecting Passenger Transfer (Chapter 16).

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Appendix B
Airport Landside Capacity Analysis Methods

A brief review is given of a range of tools and procedures that may be useful to analysts and decision makers in assessments of airport landside capacity. The specific tools and procedures presented are a cross section of the field and are not recommended as preferred for any particular situation.

A variety of rules of thumb, mathematical relationships, and computer-based simulations are available. Much of the research and many of the resulting analysis tools for terminal buildings and curb use the mathematical framework of queueing theory. Problems of motor vehicle access and parking are sometimes addressed by using techniques of highway transportation and traffic engineering.

The airport landside capacity analyst choosing among alternative analysis methods must typically strike a balance between simplicity, speed, and ease of use, on the one hand, and more detailed representation of the facilities and services of interest, greater need for data and technically trained analysts, and cost, on the other. Although methods employing greater detail and more data are generally presumed to yield more reliable results, this does not hold true for forecast data, which are inherently uncertain. Analysis tools are most likely to be useful if they help analysts and decision makers to understand better the sources of current problems and the possible consequences of selecting among alternative solutions to these problems.

Any airport's landside system is complex. There is some flexibility for the airport user to accommodate to current or anticipated conditions at the airport and to travel through the system even when queues are growing. Given the difficulty of representing such a situation, simple rules of thumb based on

observation at airports in operation may often be as useful as more complex mathematical analyses for assessing capacity. Such rules of thumb are invariably easier to apply.

Nevertheless the framework of queueing theory gives a useful structure to the analysis process. The airport terminal may be thought of as a series of active processors (e.g., baggage check, passenger security check, ticket counter, baggage claim, and parking area) tied together by a series of holding and circulation areas (e.g., passenger waiting areas and corridors).[1] As long as the average rate of arrival and the accumulated number of passengers wishing to pass through the processing element or holding or circulation area does not exceed the rate at which they can be accommodated, subject to standards defining this accommodation over the period of time in question, capacity is adequate.

Using queueing theory, the interaction among various functional components of the terminal may be explored. If a capacity problem is relieved in one component, congestion and delay may then be observed in another component downstream. Queueing models help predict when such a progression of the problem is likely to occur.

An alternative to the use of analytic models is simply comparing seemingly similar airports. The comparison may be a straightforward analogy or may use sophisticated statistical procedures to identify trends in data for many airports.

Analysis methods have been developed by using both approaches. Although many of them were developed for terminal planning and design of new facilities, they may often be adapted to terminal landside capacity analysis.

Landside capacity analysis often requires the services of a technically qualified professional. Many airports have such professionals on their staffs. Other airport operators may need the assistance of a consultant. This appendix is intended to aid the nontechnical user of these guidelines to work with technical analysts.

The methods summarized here represent levels of detail ranging from broad planning to detailed design of terminal facilities. Assessment of a potential capacity problem may require several successively more detailed levels of analysis to identify specific problems and to suggest likely solutions. Staff or consultant analysts usually use several methods of the types reviewed here in the course of assessing the landside capacity of a particular airport.

Methods are grouped into the following categories:

1. Gate and apron utilization;
2. Terminal buildings and connectors;
3. Ground access, terminal curb, and parking; and
4. Terminal system as a whole.

GATE AND APRON UTILIZATION

Many analysis methods begin with a schedule of daily flight operations that gives scheduled flight arrival and departure times by airline and aircraft turnaround times. This information is typically presented in a ramp chart. Simplified procedures compress this information into average daily statistics. Analysis methods may yield a measure of how intensively a group of gates is utilized or determine whether additional flights can be accommodated. For larger gate complexes the problems of aircraft-gate compatibility become sufficiently complex to warrant computer simulation.

The following methods are reviewed here:

- Direct calculation of gate needs
- Square-root rule
- Parsons gate-enplanement curve
- Average-to-peak utilization correction
- Gate-capacity graphic analysis
- Parsons apron area capacity estimate
- Ramp chart hourly utilization analysis
- Aggregate apron utilization efficiency
- Gate management simulation models
- Canadian gate assignment model

Direct Calculation of Gate Needs *(1)*

Procedure

- The peak-day aircraft fleet mix is listed, categorized by expected gate occupancy time.
- A weighted average service time is calculated.
- The single-gate-capacity index, in aircraft per minute per gate, is calculated as the inverse of the weighted average service time:

$$C = \frac{1}{\text{weighted service time}}$$

- Overall capacity, in number of aircraft, is the product of this index and the total number of gates at the terminal:

Capacity = $C \times$ (gates) $\times$ 60 min

- For exclusive gate use, the previous step is repeated for each group of gates under exclusive use. Total terminal capacity is then the sum of individual group capacities.

Commentary

- Use of this method implies 100 percent utilization and perfect schedule mesh. A slightly longer average occupancy time would allow for uncertainties and schedule mismatch.
- The maximum passenger capacity, if relevant, might be calculated by multiplying the flight capacity by the FAA-style equivalent aircraft (EQA) seating number for the airport's fleet mix computed with an average aircraft load factor of 1.0 (all seats full) [see Parson's manual *(2)*].
- Although the calculation is simple and fast, the method yields indicative results only and application is limited to assessments.

Square-Root Rule ***(3)***

Procedure

- A rule of thumb is cited regarding numbers of extra gates needed to allow for scheduling flexibility:

Total gates required = (gates required by current schedule) + (square root of gates required by current schedule)

- This rule implies a margin of approximately 30 percent for a 10-gate airport, declining to 8 percent (12 gates) for a large 140-gate airport.
- An "effective" number of gates could be calculated from the total gates at an airport with this rule of thumb, which would then be used in the direct calculation method to determine practical capacity.

Commentary

- The rule appears not to consider the degree of impact that exclusive gate use might have, but may be adequate as an approximation of current practice.

- The rule would have to be applied separately for widely separated unit terminals or satellites.
- Computation would presumably start with a schedule of flights at the airport.

Parsons Gate-Enplanement Curve ***(2)***

Procedure

- Plot of annual enplanements versus estimated gate positions may be inverted to read capacity for a given number of gates.
- Above approximately 4 million annual enplanements, relationship becomes linear at 300,000 annual enplanements/gate.
- Curve appears approximately parabolic below 4 million annual enplanements, so that capacity = 12,000 $\times$ (gates)^2 annual enplanements.

Commentary

- Translation to peak-hour capacity would presumably be made with standard peak-to-annual relationships, ideally specific to the airport in question.
- Relationship may be tested against current airport gate utilization data. Preliminary inspection of AOCI 1981 data suggests that curve may have merit compared with current operating practices.
- An independent verification of capacity limits would be desirable.
- The Parsons manual as a whole, although frequently criticized as very general and probably out of date, is nevertheless widely used.

Average-to-Peak Utilization Correction ***(4)***

Procedure

- Analysis of data at San Francisco International found that average gate utilization, measured in terms of time occupied on a basis of 6-min intervals, was approximately 84 percent of peak utilization.
- Such a factor could be used in conjunction with other procedures that yield annual enplanement capacities.

Commentary

- No claim of transferability can be made.
- Data from Palm Beach suggest average at approximately 64 percent of peak, perhaps indicative of the higher peaking at smaller or vacation-oriented airports.
- Easy correction factors similar to this should be developed by using data for other specific airports.

Gate-Capacity Graphic Analysis *(5)*

Procedure

- Given an average gate occupancy time for non-widebody flights and percent of non-widebodies in peak-hour flight schedule, hourly gate capacity operations base is read from graph.
- Gate size factor is read from graph, based on percentage of widebody aircraft in peak-hour flights and percentage of available gates able to handle widebodies.
- Gate capacity, in operations per hour, is computed as

C = (operations base) × (size factor) × (number of gates)

Commentary

- Full gate utilization is assumed.
- This method would be applied separately to each group of exclusive-use gates.
- Relatively easy to use, technically adequate, and officially sanctioned, this method may often be a good starting point for preliminary assessment of gate utilization problems.

Parsons Apron Area Capacity Estimate *(2, 6)*

Procedure

- Average space requirements are suggested for aircraft, including an inferred typical "all aircraft parking envelope" at 232 ft × 260 ft.

- Total space required for parking is projected at 1.41 acres/aircraft, with a range from 1.0 acre for a DC-9 to 3.7 acres for a B-747.

Commentary

- This approach uses straightforward computation and yields seemingly valid results but may seldom be relevant to capacity.

Ramp Chart Hourly Utilization Analysis *(7)*

Procedure

- A ramp chart is prepared for the average day, peak month, showing scheduled flight arrival and departure time by assigned gate.
- Gate occupancy in each hour is read from the ramp chart, or calculated as the number of aircraft on the ground in the previous hour less the number of departures in the previous hour plus the number of arrivals in the current hour divided by the number of gates.
- If occupancy is computed to be 100 percent during the governing time period, then effective capacity has been reached for that time period.

Commentary

- If capacity is to be determined on an hourly basis only, this procedure may be unnecessary. Gate capacity is simply 100 percent occupancy with the airport's current fleet mix.
- Under exclusive gate use, an airline might have flights scheduled such that there is a gate available for a full (peak) hour, so that apparent occupancy would not be 100 percent, even though no other flights could be accommodated.
- This method requires assumptions about turnaround times to compute slot availability.

Aggregate Apron Utilization Efficiency *(8)*

Procedure

- A calculation is made of the plan area of a circle with diameter equal to the length or wingspan of the aircraft, whichever is greater.

- The average use efficiency parameter, equal to the ratio of aircraft seat load to area of this circle, is calculated for the fleet currently operating at the airport.
- A similar calculation is made for the anticipated fleet mix. If average parameters (passengers per unit apron space) are significantly lower with the future fleet mix, then other design actions than addition of gates may be required to accommodate future passenger traffic growth.

Commentary

- This may be a useful and quick test of impending space constraints.

Gate Management Simulation Models

Procedure

- In a computerized system, airport physical layout, flight schedule, and fleet characteristics are specified by the user in response to prompts.
- Model assigns flights to gates, either to minimize total gates in use or with preferential assignment.
- A full 24-hr day is simulated. Graphic outputs include gate utilization statistics and diagrammatic maps of terminal building gate positions with aircraft.

Commentary

- Models are proprietary packages, available only through the consultants.
- Simulation algorithms and optimization procedures are undisclosed in available literature.
- Programs may be menu-driven and include graphic output, making them relatively user friendly.

Canadian Gate Assignment Model *(9)*

- Queueing analysis is applied to the flight schedule, using a "first-arrived, first-assigned" algorithm, but with preference given to larger aircraft, airline gate preferences, and flight sector.

- Model projects ahead to determine whether vacant gates should be held open for "more deserving" approaching aircraft.
- Up to a full operating day can be simulated according to user-specified assignment strategy and aircraft-gate compatibility to minimize aircraft and passenger delays.

Commentary

- The model is programmed for IBM-compatible microcomputers.
- The model can be calibrated to accommodate common-use, exclusive-use, or preferential-use assignment strategies or combinations of these strategies.
- Currently the model is available for Transport Canada applications.

TERMINAL BUILDINGS AND CONNECTORS

Queueing theory underlies many of the models and rules of thumb for terminal buildings and connectors. Departing and arriving flows are generally considered separately, and attention must be given to those who accompany passengers through parts of the system. Capacity is determined in all cases essentially by the number of people who can be accommodated in a period of time.

The following methods are reviewed here:

- Terminal concept capacity ranges
- Parsons manual planning standards
- Simple queueing formula
- Airport Terminal Simulation Model (ATSIM) and Terminal Area Capacity Simulation Model
- Canadian Terminal Simulation Model

Terminal Concept Capacity Ranges *(2, 6)*

Procedure

- Parsons manual and FAA circular give broad guidance on relevance of terminal concepts for airports expected to operate at various broad volume levels. See Figure B-1.

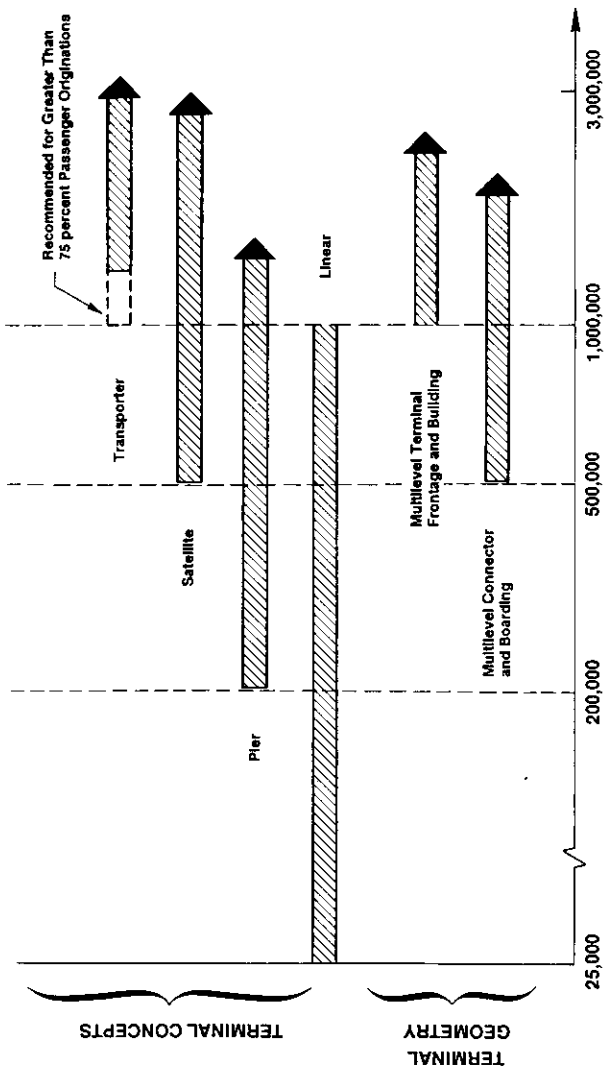

FIGURE B-1 Capacity aspects of terminal concepts *(2, 8)*.

- If future operations are likely to grow beyond the transition levels where alternative concepts are workable, a capacity problem might be indicated.
- It is suggested that 1 million annual enplanements represents a basic transition of airport type, and that landside capacity issues are more likely to be substantial as traffic grows through the range of 0.5 to 1.0 million annual enplanements.

Commentary

- Information should perhaps be considered within context of relationships between terminal siting and runway configuration (Figure B-2).
- As a simple broad indicator of generally accepted conventional wisdom this method may be a useful starting point for consideration of capacity problems.

Parsons Manual Planning Standards *(2, 6)*

Procedure

- Planning relationships and standards may be used to establish whether a particular airport's current operation is consistent with what had been planned to meet current demand.
- For example, planned gate utilization is permitted to grow to as much as 300,000 to 450,000 annual enplanements per gate. If the most heavily loaded 10 percent of gates at an airport exceed these levels annually, perhaps capacity is being approached.
- Standards may be inferred for the following additional elements of the system:

  - Baggage processing and claim areas;
  - Baggage claim equipment type and passenger service perimeter where bags are taken;
  - Concessions and lobby areas;
  - Ticket counter frontage and queueing areas;
  - Customs and immigration queueing area, manual processing positions, and total area; and
  - Gross terminal building floor area related to number of gates.

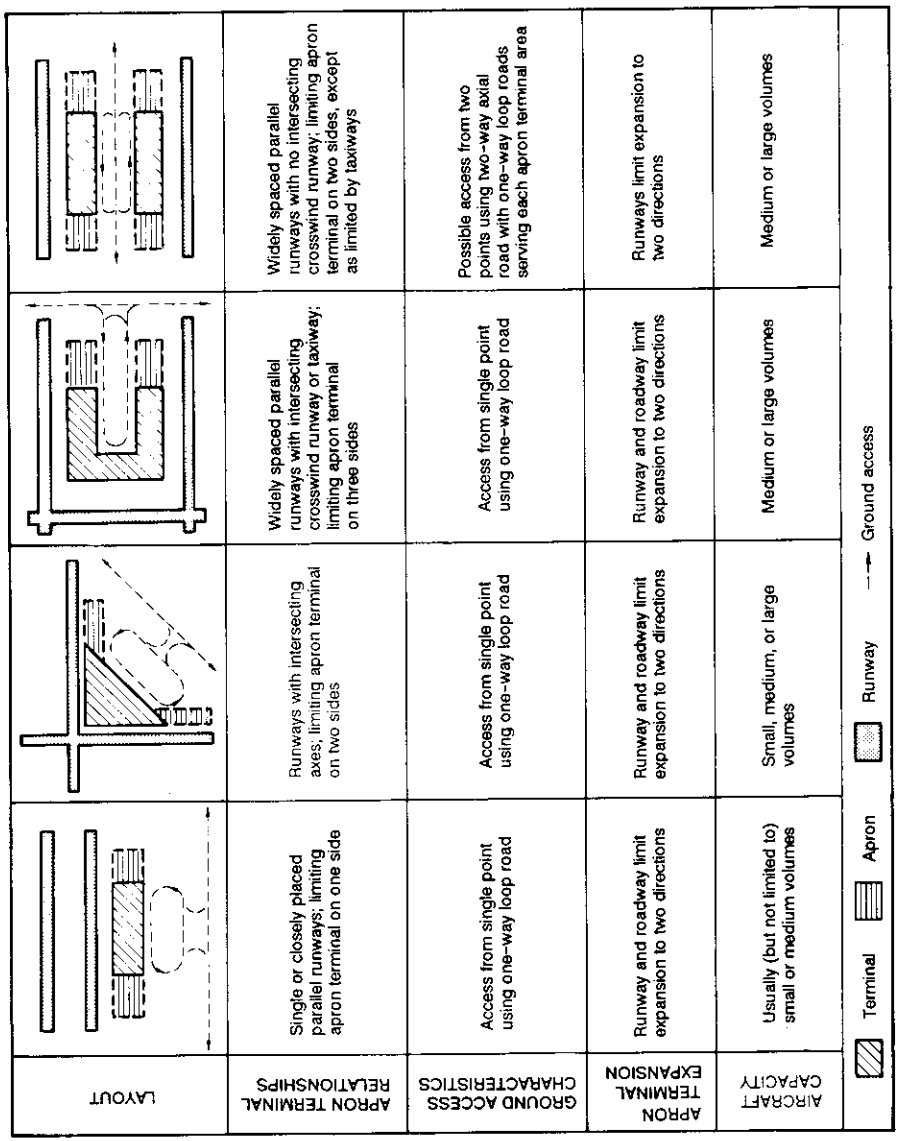

FIGURE B-2 Relationships between terminal site and runway configuration (*2, 6*).

Commentary

- Entire manual could in principle be "run in reverse" to compute annual and hourly enplanements from given physical facilities measures. However, age of material makes some of the relationships particularly open to question.

Simple Queueing Formula *(12)*

Procedure

- Major service points in the system are treated as single-channel or multichannel service facilities modeled by queueing theory. Passengers arrive at some known rate, are given service at some rate (generally assumed to be fixed at some average service time), and move to the next element of the system. Queues form if arrivals rate exceeds service rate. The queue length, expected total service time (including any waiting in a queue), and time for queues to clear may be calculated, and depend on the underlying mathematical distributions of arrival and service times assumed to apply.
- If passenger arrivals are assumed to be random, the Poisson process may be used. With service times assumed to be described by an exponential model, average delay time at the processing point and average number of people waiting for service (queue length) are calculated as follows:

$$T = \frac{a}{s(s-a)}$$

$$N = \frac{a^2}{s(s-a)}$$

where

T = average waiting time,
N = average number of people waiting,
a = arrival rate, and
s = service rate.

Field observations or assumptions based on the design of the airport and its flight schedule may be used to estimate the parameters s and a during the peak hour. Calculated wait time and the ratio of calculated number of people waiting to the available waiting area may be compared with standards.

- Similar assumptions yield a model of waiting time at baggage claim:

$$T = t(2) + \frac{nt(3)}{n+1} - t(1)$$

where

T = average waiting time,
n = average number of bags per passenger,
$t(1)$ = expected length of time from flight arrival for all passengers to arrive in claim area,
$t(2)$ = expected length of time from flight arrival for first luggage to reach claim area, and
$t(3)$ = expected length of time between arrival of first bags and last bags at claim area.

Commentary

- Canadian government studies demonstrate how standardized accumulation curves could be developed for each waiting area in a particular airport.
- A major difficulty with this approach is that often passenger arrivals at service points are platooned rather than random. Assessment of a single hour for capacity determination is particularly sensitive to clustered arrivals.

Airport Terminal Simulation Model (ATSIM) (Aviation Simulations International) and Terminal Area Capacity Simulation Model (Peat, Marwick, Mitchell and Co.)

Procedure

- The airport terminal layout is blocked off into movement areas and nodes, each characterized by passenger processing statistics. Scenarios describing passenger behavior then are specified for the model's discrete-event simulation of passenger movement through the system. The model routes passengers in response to the basic behavioral scenario and congestion encountered because of earlier passenger arrivals.
- An alternative approach is based on time-stepped simulation, which operates relatively faster and with less computer capability required, but at some small loss of accuracy.

Commentary

- These models are examples of proprietary tools developed by a number of consultant organizations.

Canadian Terminal Simulation Model (Transport Canada)

Procedure

- Computation procedure not yet available.

Commentary

- The present model will operate only on Transport Canada's mainframe computer. The program is being rewritten to run on IBM-XT-compatible microcomputers and is expected to be completed in 1987.

GROUND ACCESS, TERMINAL CURB, AND PARKING

Ground access, the terminal curb, and parking serve motor vehicles, and although some simple models and rules of thumb have been devised, detailed assessment of these components is likely to require assistance of a qualified traffic and transportation analyst. Methods of analysis are described in such standard publications as the *Highway Capacity Manual (10)*, published by the Transportation Research Board, and the *Transportation and Traffic Engineering Handbook* of the Institute of Transportation Engineers *(11)*.

Transportation professionals involved in airport planning and design have adapted some standard procedures to the specific needs of the airport. The terminal curb has been a particular focus of such work. Simulation models have been used to analyze parking lot operations.

The following methods give an overview of the range of planning and design procedures that may be adapted to capacity assessment:

- Access capacity-to-demand index
- Parking requirement planning curve

- Curbside queueing model
- Taxi Operations Simulation (TAXISIM)
- Curbside level-of-service planning method

Access Capacity-to-Demand Index *(13)*

Procedure

- A passenger demand index is calculated as

PDI = [1.5 (daily passengers minus interline transfers) + 2 (no. of airport employees)]/1,000

This index is meant to approximate the number of trips per day made to the airport.

- An access supply index is calculated as

PCI = 3.1 [effective lane capacity (vehicles/hr)]/1,000

This calculation implies an assumed average vehicle occupancy rate of 3.1 persons/vehicle.

- If the ratio *PDI/PCI* is greater than 1.0, there is a potential capacity problem.

Commentary

- Such indexes reflect the underlying principles for access capacity analysis. The multipliers used could be changed to suit conditions at an individual airport. However, such indexes can only be first approximations, useful for initial screening for problems.

Parking Requirement Planning Curve *(3)*

Procedure

- Planning standards reflected in relationships such as that shown in Figure 12-1 may be "inverted" to estimate capacity of facilities in place.
- Given a number of available parking spaces, the implied range of acceptable passenger loads may be estimated.

Commentary

- Such relationships may be useful first indicators of problems, but may not fit the specific conditions at a particular airport.

Curbside Queueing Model *(14)*

Procedure

- The curbside operation is described as a standard queueing model and standard tables and graphs are used to solve for queue times or space requirements.
- Vehicle arrival rates and mean dwell times are required to calculate required curb length for given demand.

Commentary

- The approach illustrates the analytical benefits of being able to use a simple single-channel queueing model to represent a part of the terminal landside. Nomographs are available or can be constructed for solving problems.

Taxi Operations Simulation *(15)*

Procedure

- Average passsenger arrival and trip characteristics are input to this computerized simulation model, along with fare and fee data.
- Taxis in use and average fleet utilization statistics are projected.
- Financial analysis of the projections indicates whether improved fleet profitability can be achieved without reduction of passenger service levels.

Commentary

- Such models are typically developed for specific applications.

Curbside Level-of-Service Planning Method *(6)*

Procedure

- Given peak-hour enplaning or arriving passengers and available curb frontage, level of service is projected by the graph shown in Figure 11-2. Levels of service are analogous to those in the *Highway Capacity Manual.*
- Underlying formulas and adjustment factors are used to respond to specific conditions at an airport, such as vehicle dwell time, arrival rate, and vehicle fleet mix.

Commentary

- The procedure is based on an assumed steady rate of arrival of vehicles and passengers during the peak hour and is consistent with queueing models.

TERMINAL SYSTEM AS A WHOLE

Analyses of individual component capacity may fail to recognize important functional linkages within the system. Analysts have tried to overcome this problem by constructing simulations of the terminal as a whole. These models are typically complex computer simulations, reflecting the complexity of the terminal landside system. Similar results can in principle be achieved by linking separate component models together, but interaction among components may then be poorly represented.

The following methods are reviewed here:

- Airport Landside Simulation Model (ALSIM)
- Spreadsheet equivalent capacity analysis
- Performance simulation using SLAM

Airport Landside Simulation Model (ALSIM) *(17)*

Procedure

- Details of flight schedule, ground transport demand and schedules, airline operations, airport operations, and passenger charcteristics are input to a mainframe computer program. Mean service times and standard deviations are required for most items. The airport is modeled as a Markov network, with transition probabilities calculated from input data. Defaults are available for many parameters.

- Iterative simulation of passenger movements through the terminal landside system produces estimates of expected peak-hour mean passenger delay and cumulative delay (in passenger-minutes) and annual cumulative delay. Statistics are shown for individual components as well as for the system as a whole.

Commentary

- This model, developed by the FAA, was one of the most comprehensive attempts to model the terminal landside as a whole. It was intended to be generally applicable and was in the public domain.
- The model was not widely used and is now effectively dormant.

Spreadsheet Equivalent Capacity Analysis *(9)*

Procedure

- Each major component of the airport is represented as a simple processor or hold area; average service rate or holding capacity is specified. The system is presented in a standard accounting spreadsheet format.
- Maximum theoretical hourly capacity of each component is calculated and used to estimate a maximum theoretical airport service volume.

Commentary

- This straightforward accounting framework is an example of the type of work made practical by interactive use of microcomputers. Although the underlying model is simplified compared with stochastic simulations, the results may be equally useful.

Performance Simulation Using SLAM *(18)*

Procedure

- The terminal landside system is represented as a multi-channel queue service facility, using exponential and Erlang distributions of service times.
- A standard simulation language, in this case SLAM, is used to project consequences of various service volumes in terms of delay times (per passenger and cumulative), queue lengths, and utilization levels of servers.

Commentary

- This approach is similar to that underlying the ALSIM model. In contrast to ALSIM, the user must be familiar with the simulation language and the technical assumptions involved in selecting service time distributions.

NOTE

1. Transport Canada and IATA guidelines adopt a three-part characterization: processors, reservoirs, and links among the first two types of components.

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Study Committee Biographical Information

MARJORIE BRINK, *Chairman*, has had 25 years' experience as an airport planning consultant. She graduated from Indiana University and was a member of Phi Beta Kappa. She has prepared basic research studies leading to the airside-landside separation concept used for developing the world-renowned passenger terminal facilities at Tampa International Airport, which was opened in 1971. (The terms "airside" and "landside" were created as a part of this research project and have since become standard terminology in the industry.) Ms. Brink is responsible for a number of airport master plans that involved comprehensive analysis of landside capacity, including those for major airports in Tampa, Portland, Tucson, and Nashville. The author of many reports and articles, she is a principal with Peat Marwick Airport Consulting Services.

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J. Donald Reilly is Executive Director and Secretary General of the Airport Operators Council International. He received a B.S. in Economics from Franklin and Marshall College and an L.L.B. from George Washington University Law School. Mr. Reilly has been with the AOCI since 1961. In 1965 he was appointed Director of Legal Services, a post he held until he was made Executive Director in 1968. He serves as Chairman of the Industry Task Force on Airport Capacity Improvement and Delay Reduction, which reports to the Administrator of the Federal Aviation Administration on many operating procedures and research needs to improve air transportation capacity, with a primary focus on the airside.

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The Transportation Research Board is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

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The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

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