Evaluating Airfield Capacity

DETAILS

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

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

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FOREWORD

By Theresia H. Schatz
Staff Officer
Transportation Research Board

ACRP Report 79: Evaluating Airfield Capacity provides a guidebook and accompanying CD-ROM to assist airport planners with airfield and airspace capacity evaluation at a wide range of airports. The guidebook describes available methods for evaluating existing and future airfield capacity; provides guidance on selecting an appropriate capacity analysis method; provides best practices in assessing airfield capacity and applying the modeling techniques; and outlines specifications for new models, tools, and enhancements. The guidebook includes relevant background information on airfield components and operations, descriptions of existing modeling tools, explanations of new modeling tools created as part of this research, and a decision-support tool to help select a capacity evaluation technique. The accompanying CD-ROM provides prototype capacity spreadsheet models that are designed to be a preliminary planning tool, similar to the Airfield Capacity Model (ACM) but with more flexibility to change input assumptions to represent site-specific conditions from the most simple to moderate airfield configurations.

Airfield capacity assessment is a critical evaluation component of most airport planning projects; therefore, it is important that appropriate guidance be available to the aviation industry for estimating airfield capacity. While airport sponsors often employ more sophisticated methods for evaluating capacity, the FAA's Advisory Circular 150/5060-5, *Airport Capacity and Delay* (the AC), is the current formal FAA guidance on this topic. To use the AC, airport planners must choose one or more lookup tables or nomographs that, singly or collectively, most closely match the airport's runway layout. There are also complex, higher fidelity simulation models, such as SIMMOD and TAAM, which can be resource- and data-intensive. With the many current and evolving factors and limitations that influence airfield capacity at a given airport, there was a need to enhance existing capacity-modeling tools and techniques to provide the accuracy appropriate to support timely and cost-effective project funding decisions.

This research was developed under ACRP Project 03-17, "Evaluating Airfield Capacity," by a team of recognized experts in airport planning, air traffic control, airfield operations, and airfield and airspace capacity. LeighFisher led the research effort in association with Landrum & Brown; CDM Smith; George Mason University; University of California, Berkeley; and Presentation & Design, Inc.

Appendix A to this guidebook provides a User's Guide for the Prototype Airfield Capacity Spreadsheet Model, and Appendix B provides essential references and data sources. The Prototype Airfield Capacity Spreadsheet Model is contained on the accompanying CD-ROM.

A separate final report, which provides background to the research conducted in support of the guidebook, has been posted on the ACRP Project 03-17 web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2579.

CONTENTS

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

CHAPTER 1

Introduction and Background

ACRP Report 79: Evaluating Airfield Capacity is the end product of ACRP Project 03-17 of the same name, which was undertaken in 2009 with the primary objective of developing a guidebook to assist airport planners with airfield and airspace capacity evaluation at all types of airports. Specific objectives were established for the guidebook, as follows:

- Assess relevant methods and modeling techniques for evaluating existing and future capacity for airports beyond those outlined in the current FAA's Advisory Circular 150/5060-5, *Airport Capacity and Delay* (hereinafter referred to as the AC) or the Airfield Capacity Model (hereinafter referred to as the ACM)
- Identify the limitations of the existing techniques and develop specifications for new models, tools, or enhancements
- Present capacity modeling guidelines that would improve the decision-making process for determining the appropriate level of modeling sophistication for a given planning study
- Present a functional prototype of one or more modeling tools

This introductory chapter provides general background information, addresses specific factors that shaped the development of the guidebook, and outlines its organization.

Introduction

The AC is dated September 1983 and was updated twice through 1995 (see Figure 1-1). FAA has been considering a third update to the AC; however, the publication date for this update was unknown at the time this report was prepared.

ACRP Report 79 is not intended to describe how to use specific airfield capacity models. Moreover, it does not address the capacity of any airport component other than the airfield, which is defined as runways, taxiways, aprons, holding bays, and close-in terminal airspace. For the purposes of this guidebook, airfield capacity is limited to the runway system and supporting airspace and taxiways that influence runway capacity (i.e., runway exit taxiways, departure hold pads, and parallel taxiways). Aircraft delay and its relationship to airfield capacity are mentioned only briefly in *ACRP Report 79;* this topic is being addressed in ACRP Project 03-20, "Defining and Measuring Aircraft Delay and Airport Capacity Thresholds," currently under way.

The guidebook provides a review of current FAA guidance on airfield capacity and highlights other methodologies and tools currently available in the public and private domain relative to the topic. In addition, prototypes of new airfield capacity spreadsheet tools were developed that provide additional mechanisms for calculating airfield capacities. The guidebook also provides

Source: Federal Aviation Administration.

Figure 1-1. FAA Advisory Circular 150/5060-5, Airport Capacity and Delay.

decision-support tools that can be used in selecting the appropriate level of modeling sophistication for a given application and set of circumstances.

Intended Audience

The guidebook's intended audience includes a wide range of potential users, such as airport operators, regional planning agencies, state aviation agencies, airport consultants, aviation researchers, FAA planners, and other public and private aviation organizations. It has been assumed that users of this guidebook will have a general understanding of an airport's facilities and operations, particularly with regard to the airport for which a capacity analysis is being considered. Members of the intended audience will (1) know how an airfield is typically operated in terms of aircraft taking off and landing, (2) be able to obtain at least minimal data on the airfield and air traffic to be analyzed, and (3) be able to use the recommended criteria for selecting an appropriate evaluation technique given the specific characteristics of the airport or airfield under consideration.

The guidebook provides information useful to both novice and experienced airport planners seeking to do the following:

- Understand basic airfield elements and operations
- Understand the definition of airfield capacity
- Review the tools currently available to estimate airfield capacity, including new tools made available as a result of this research project
- Select the appropriate tool or level of modeling sophistication for the airport and the purpose of the airfield capacity analysis
- Compile the data necessary to conduct the capacity analysis
- Apply the selected tool to obtain the desired estimate of hourly or annual airfield capacity.

Overview of Airfield Capacity

The research for this project focused specifically on the capacity of runways and close-in terminal airspace. The term *airfield* generally refers to close-in terminal airspace, runways, taxiways, apron areas, and holding bays. However, airfield capacity should be in balance with the capacities of the terminal building and landside capacities.

Airfield capacity estimates are used to address airport planning issues by a wide range of persons and organizations (e.g., airport operators, regional planning agencies, state aviation agencies, airport consultants, and FAA planners, among others). Airfield capacity estimates are used for various purposes and can be obtained using different methods that reflect the level of detail needed. Some airport planning analyses are conducted with an emphasis on airfield capacity, while others may only reference capacity without requiring detailed evaluations.

Definitions of airfield capacity vary depending on the source or audience. The AC defines capacity in terms of an airport's *throughput* capacity; that is, as a measure of "the maximum number of aircraft operations which can be accommodated on the airport or airport component in an hour."[1]

In the original research that led to the development of AC 150/5060-5, considerable effort was expended on reaching a single concept of capacity. In practice, however, at least two definitions of capacity remain widely used: (1) a measure of maximum sustainable throughput similar to the definition in the AC, and (2) a measure of practical capacity defined as the number of aircraft operations that results in a specified maximum average delay. Both of these definitions have validity and are intended to answer different questions.

- **Maximum sustainable throughput** answers the question, "How many aircraft operations can an airfield reasonably accommodate in a given period of time when there is a continuous demand for service during that period?"
- **Practical capacity (or service volume)** answers the question, "How many aircraft operations can an airfield accommodate at a specified level of service?" Level of service typically is defined in terms of a threshold level of average annual aircraft delay (e.g., 7 minutes per aircraft operation).

FAA also has defined capacity in terms of specific time intervals. The two most commonly used time intervals are hourly and annual. Hourly airfield capacities can be calculated using the AC for different runway configurations and weather conditions in terms of cloud ceilings and visibilities at the airport. Annual airfield capacity—referred to in the AC as annual service volume (ASV)—is an estimate of how many aircraft operations an airport can accommodate in a year, and can also be calculated using the methods in the AC.

ACRP Report 79 focuses on the maximum sustainable throughput definition of capacity. The word *sustainable* was added to the definition in the AC to reflect the fact that actual flow rates at congested airports often exceed estimated capacities over very short time intervals, but such actual rates usually are not sustainable for an entire hour.

This definition is more consistent with the current FAA practice of estimating airfield capacity, in particular as set forth in FAA's recent airport capacity benchmark reports. At publication of ACRP Report 79, the most recent such report available to the public was the *Airport Capacity Benchmark Report 2004* (see Figure 1-2). FAA plans to release the next updated report in 2012.

The airport capacity benchmarks reported in the foregoing FAA reports are presented using capacity curves (also called Pareto frontiers). In Figure 1-3, a capacity curve is shown as a solid

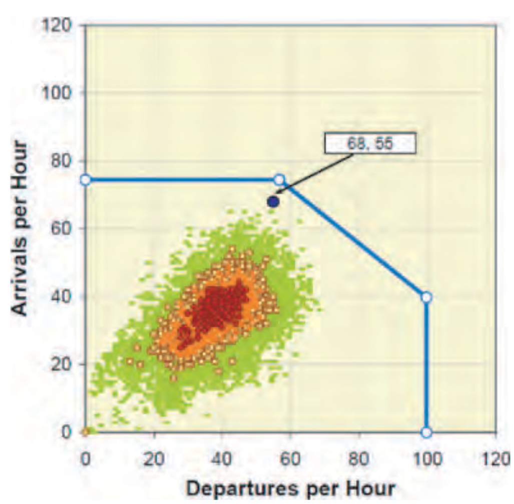
[1]FAA AC 150/5060-5, Airport Capacity and Delay, available at http://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5060_5.pdf (accessed 8-24-12).

Source: Federal Aviation Administration.

Figure 1-2. FAA Airport Capacity Benchmark Report 2004.

line. In this figure, the point where the solid line intercepts the vertical axis is the arrivals-only capacity; the point where the solid line intercepts the horizontal axis is the departures-only capacity; and any point along the curve represents the maximum sustainable throughput for that combination of arrivals and departures. Further information about developing and interpreting capacity curves is presented in later chapters of this guidebook.

Defining airfield capacity in terms of maximum sustainable throughput also is more consistent with airport arrival rates (AARs) and airport departure rates (ADRs) as defined by FAA's Air



Source: Federal Aviation Administration.

Figure 1-3. Capacity curve from FAA Airport Capacity Benchmark Report 2004.

Traffic Organization (ATO) for purposes of its air traffic management initiatives. FAA defines AAR and ADR as follows:

- **AAR:** The number of arriving aircraft which an airport or airspace can accept from the ARTCC [Air Route Traffic Control Center] per hour.
- **ADR:** The number of aircraft which can depart an airport and which the airspace can accept per hour.[2]

The maximum sustainable throughput definition of capacity is most useful for comparing demand and capacity and as input to analytical models for estimating aircraft delay. This definition of capacity is most relevant to the objectives of this guidebook, for two reasons.

1. Capacity, by itself, is not a very useful measure unless it is compared with some measure of demand.
2. The most useful demand-capacity comparisons are the ones that provide decision makers additional performance metrics, such as aircraft delay, the ability of the airfield to accommodate existing and projected airline schedules, and, in extreme cases, cancellations and diversions.

As a result, *ACRP Report 79* includes guidance on defining and estimating airfield capacity on an hourly basis for use in making appropriate demand-capacity comparisons and for input to currently available analytical models used to estimate aircraft delay. The treatment of delay and its relationship to capacity is being addressed in ACRP Project 03-20, "Defining and Measuring Aircraft Delay and Airport Capacity Thresholds."

Existing FAA Guidance

In 1983, FAA published the AC to replace advisory circulars that had been published in 1968 and 1969 and to provide a significant update to previous guidance on airport and airfield capacity calculations. Subsequently, two changes were published to update sections of the AC, including an entire rewrite of the chapter on computer programs for calculating airfield capacity and aircraft delay that was published in 1995. Computer programs noted in the AC include:

- Airport and Airspace Simulation Model (SIMMOD)
- The Airport Machine
- Airfield Delay Simulation Model (ADSIM)
- The ACM

The AC and the models developed by FAA are the primary resources used by aviation planners to calculate capacity for all types of airports, large and small. While FAA and others often use more sophisticated methods for evaluating airfield capacity, the AC is the only formal guidance on this topic, and it was last updated in 1995.

Existing Analytical and Computer Simulation Models

Models used to analyze capacity typically can be categorized as either analytical models or computer simulation models. **Analytical models** use a series of equations to calculate results and do not explicitly use random variables or Monte Carlo sampling techniques.[3]

[2]Sources: "Pilot/Controller Glossary," which is an addendum to the FAA Aeronautical Information Manual; Order JO 7110.10, Flight Services; Order JO 7110.65, Air Traffic Control; accessed on February 16, 2012, at: http://www.faa.gov/air_traffic/publications/atpubs/pcg/

[3]Monte Carlo sampling is a problem-solving technique used to approximate the probability of certain outcomes by running multiple trials using random variables.

Table 1-1. Examples of analytical and simulation models (partial list).

Analytical Models	Simulation Models
FAA Airfield Capacity Model (the ACM)	Jeppesen-Boeing Total Airspace and Airport Modeler (TAAM)
Logistics Management Institute (LMI) Runway Capacity Model	FAA Airport and Airspace Simulation Model (SIMMOD)
Flight Transportation Associates (FTA) Runway Capacity Model (RUNCAP)	FAA Airfield Delay Simulation Model (ADSIM)
Boeing Co. Airport Capacity Constraints Model	MITRE Corporation *runway*Simulator

Simulation models generally are fast-time models that emulate the movement of aircraft using statistical sampling techniques, including random variables or Monte Carlo sampling techniques. As measured in a simulation model, time may be faster than real time, match real time, or be slower than real time, depending on the complexity of the simulation. With a fast-time model, the time required to run the simulation is less than real time (i.e., 1 minute of simulation time generally equals more than 1 minute of real time). The term *non-real time* has been adopted recently to allow for large-scale simulation models that take longer to run than real time. Most simulation models used to analyze airfield capacity are fast-time models.

Numerous analytical and computer simulation models have been developed to evaluate airfield capacity. The 1995 update of the AC identifies four models that were available at the time the AC was published to evaluate airfield capacity. Since that time, numerous other models have been developed. These models require a variety of inputs and levels of detail, mostly providing some greater level of sophistication in the analysis results than the models referenced in the AC. A partial list of the models evaluated as part of ACRP Project 03-17 is provided in Table 1-1.

In general, these models differ in several aspects, including methods to address or include the following variables:

- Airfield layout geometry (e.g., runways, taxiways, aprons, holding bays, and gates)
- Aircraft mix and airline scheduling factors (e.g., demand pattern and wake-turbulence categories)
- Aircraft performance (e.g., final approach speeds and runway occupancy times)
- Runway use and air traffic control (ATC) procedures (e.g., runway use restrictions and aircraft separation requirements)
- Weather conditions (e.g., ceiling, visibility, wind speed, and wind direction)
- Human factors (e.g., aircraft delivery accuracy and variability in response times)
- Airspace (e.g., number of runway headings and length of common final approach paths)

The differences in the models and their applications are discussed in Chapter 3 of this guidebook.

Need to Update Airfield Capacity Evaluation Methods and Guidance

The need to update airfield capacity evaluation methods results from (1) shortcomings in the existing methods, and (2) developments in technology since most of the evaluation methods were developed. In particular, the following factors in the AC have been identified as requiring an update based on changes that have occurred since publication of the AC:

- ATC rules and procedures
- Technologies associated with flight procedures, aircraft navigation, ATC surveillance, and pilot-controller communications
- Aircraft type performance characteristics
- Airport design standards
- Availability of data on aircraft operations and performance

For example, since the most recent update of the AC in 1995, ATC procedures have changed, new aircraft types have been introduced, and new navigation technologies have been implemented. These changes have not been addressed in new FAA guidance to date, although they are being considered in FAA's plans to update the AC.

Given the many current and evolving factors and limitations that influence airfield capacity at a given airport, there is a need to enhance capacity modeling tools and techniques to provide the airfield capacity estimates appropriate to make timely and cost-effective project funding decisions.

Shortcomings of Existing Methods

Existing methods of capacity evaluation were developed decades ago, and therefore do not reflect recent changes in airfield and ATC standards and procedures. In addition, they do not reflect the significant changes in computer technologies, software, and data availability that have occurred since their development.

Treatment of Complex Airfields

Over time, runways have been added to major airports to accommodate increasing traffic, which has resulted in much more complex airfield operations and increased airspace interactions between neighboring airports. The airfield capacity of these complex airfields has become more difficult to estimate using existing methods. Many large airports have runway layouts and use configurations that were not considered in the AC or other existing evaluation methods.

In trying to use the current AC and the ACM, it is often difficult to choose nomographs or models that can accurately estimate capacity for a complex airfield. Many of the more recent complex airfields are not represented in the current AC, and runways are often used differently from the way they are assumed to be used in the current AC. For example, different types of aircraft may use different runways, or site-specific runway dependencies or noise abatement constraints may exist. The operators of many larger airports with more complex airfields and capacity shortfalls have used various analytical and computer simulations either mentioned in the AC and enhanced since 1995, or developed since that time by consulting firms or other private entities.

Additionally, the types of capacity questions that need to be addressed have become more airport-specific. Instead of evaluating the potential capacity gains associated with major infrastructure improvements, the capacity issues being addressed more frequently have become airport-specific and are often based on changes in airfield and ATC standards and procedures, such as airspace constraints, the Next Generation Air Transportation System (NextGen) improvements, departure-sequencing capabilities, or the effects of current or proposed noise abatement procedures.

The complexity of airfields and the increasing specificity of capacity issues to be addressed have necessitated the more frequent use of simulation models to address airfield capacity issues. Certain situations and capacity issues require the fidelity of a simulation model; however, for certain other capacity issues that do not require this level of fidelity, there is currently no middle ground between existing AC analytical models and detailed airfield and airspace simulation modeling.

Treatment of Small Airports

Airfield capacity issues for small airports are quite different from those for larger airports. Oftentimes, airfield capacity is not a known or recognized issue at a small airport, and detailed capacity analyses are not undertaken. Attributes of small airports that often must be accounted for include:

- Presence or absence of an Airport Traffic Control Tower (ATCT)
- Presence or absence of commercial passenger service
- Presence or absence of instrument approach procedures
- Presence or absence of certain airfield infrastructure, such as a full-length parallel taxiway
- Level of flight-training or touch-and-go operations

As defined in the AC, capacity is calculated in terms of a maximum throughput rate, but this definition is not always used by the operators of small airports or their consultants in evaluating capacity. The term capacity can have implications as diverse as the airport industry itself.

For the majority of small airports (e.g., as defined in terms of either activity level, airfield complexity, type of service, or lack of ATC/flight procedures), capacity defined as a throughput rate is adequate, and calculating aircraft delay is seldom a concern. The volume of aircraft activity at a small single- or two-runway airport does not ordinarily approach the airfield capacity limit that would be estimated using the AC methodology. Unfortunately, this being the case, the operators of most small airports or airports without a definitive capacity issue will simply view capacity analyses as a basic requirement of a master planning process that has few implications for them beyond providing a capacity estimate for their master plan.

Moreover, staff and consultants at small airports often lack the resources, expertise, or need to use more sophisticated capacity evaluation methods, such as the ACM or available simulation models.

However, these airports can still experience capacity constraints, which would not be measured appropriately by available airfield capacity analysis techniques. For example, many airports experience capacity issues only in the peak hour. Local fleet mix considerations can have a dramatic effect on the operational efficiency of an airport, as can the types of aircraft operations accommodated. Consideration of these specific factors, among many others, is the reason that planners typically rely more on local knowledge and professional judgment to gauge capacity at these types of airports than on the methodologies in the AC. Stated simply, the methodology in the AC, which is the current standard for assessing capacity at smaller and less complex airports, does an inadequate job of measuring potential intricacies and nuances. The challenge is to develop a methodology that is accessible and usable by small airport operators that gives them the flexibility to obtain a meaningful measure of airfield capacity.

Recent Developments Affecting Airfield Capacity Evaluation Techniques

Many developments have occurred since the majority of modeling tools, including the AC, were developed. In particular, the following three major developments have had a major effect:

1. Increased computing power and spreadsheet capabilities
2. Increased data availability
3. Introduction of NextGen and new ATC procedures

Spreadsheet Models/Computing Power

The availability of spreadsheet models and significantly increased computer processing capability have provided low-cost analysis techniques and new methods for explicitly considering capacity factors previously addressed implicitly or through post-processing. Existing computer models for estimating airfield capacity were developed several decades ago, in an environment where mainframe computers could occupy an entire room. Desktop and laptop computers are now commonplace and have considerable processing power. The advances in computing power have led to the development of modeling tools that encompass widely used spreadsheet software and are able to calculate capacity within the model, rather than having to rely on post-processing to capture certain factors.

Data Availability

The greatly increased availability of data is an important recent development in measuring and modeling airfield capacity. New and improved databases of airport-related information have become available. Detailed information on airport hourly throughput rates is available from FAA's Aviation System Performance Metrics (ASPM) database for certain airports. Radar data are now available from FAA, and from a number of widely used Airport Noise and Operations Monitoring System (ANOMS) installations, in a form that is accessible and usable by certain airport operators. Aircraft ground movements are now captured and displayed by Airport Surface Detection Equipment, Model X (ASDE-X) at airports that have this equipment in place.

Hourly throughput and its influencing factors can now be measured precisely for a variety of weather conditions, time periods, and runway use configurations. The availability of these data has the potential to improve the fidelity of existing and proposed airfield capacity models by making them more data-driven. Primarily for larger airports, it is now possible to obtain more accurate estimates of factors that affect capacity (e.g., aircraft separations, runway occupancy times, fleet mixes, flight tracks, and so forth).

However, there remains a challenge in that some of these data are unavailable, costly to acquire, or require significant and time-consuming post-processing efforts to yield useful metrics.

NextGen/New ATC Procedures

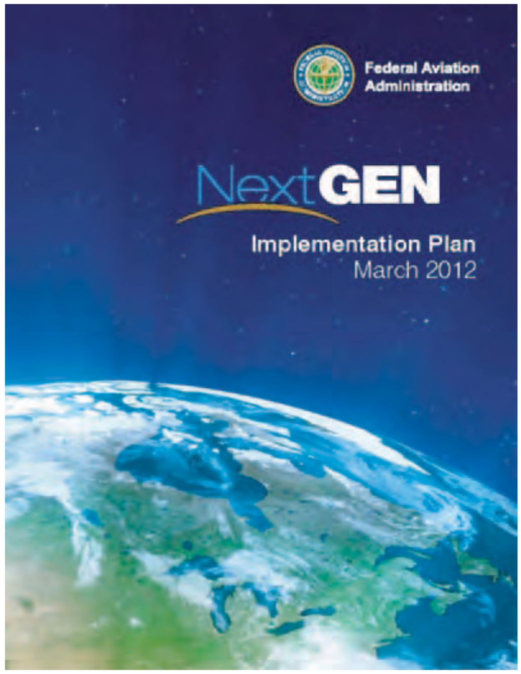
NextGen is a set of evolving ATC and aircraft navigation technologies designed to transform the U.S. ATC system from a ground-based system to a satellite-based system. The development of NextGen has resulted in the need to estimate the capacity benefits expected from the program.

Many of the existing modeling tools are not flexible enough to model such changes to procedures, aside from the more sophisticated analytical and simulation models. There is a need to also be able to evaluate the capacity benefits of NextGen improvements, and to account for the expected changes associated with the new technologies and procedures using accessible analytical models. Expected changes associated with NextGen are documented in FAA's *NextGen Implementation Plan,* the latest version of which at the time of this writing is dated March 2012 (see Figure 1-4). Chapter 4 of this guidebook discusses how some of these NextGen changes are expected to affect the factors and assumptions used to analyze airfield capacity.

Organization of the Guidebook

ACRP Report 79 is organized to be a practical and user-friendly reference tool that can assist airport planners in understanding airfield capacity and determining the most appropriate level of modeling sophistication to use for a given planning analysis and set of circumstances. This guidebook consists of six chapters and two appendices. Figure 1-5 shows the various guidebook chapters and the questions they are intended to address.

- **Chapter 2, "Airfield Capacity Concepts,"** describes the existing components of an airport that are relevant in an airfield capacity analysis. The specific factors that affect airfield capacity are also presented.



Source: Federal Aviation Administration.

Figure 1-4. FAA's NextGen Implementation Plan, March 2012.

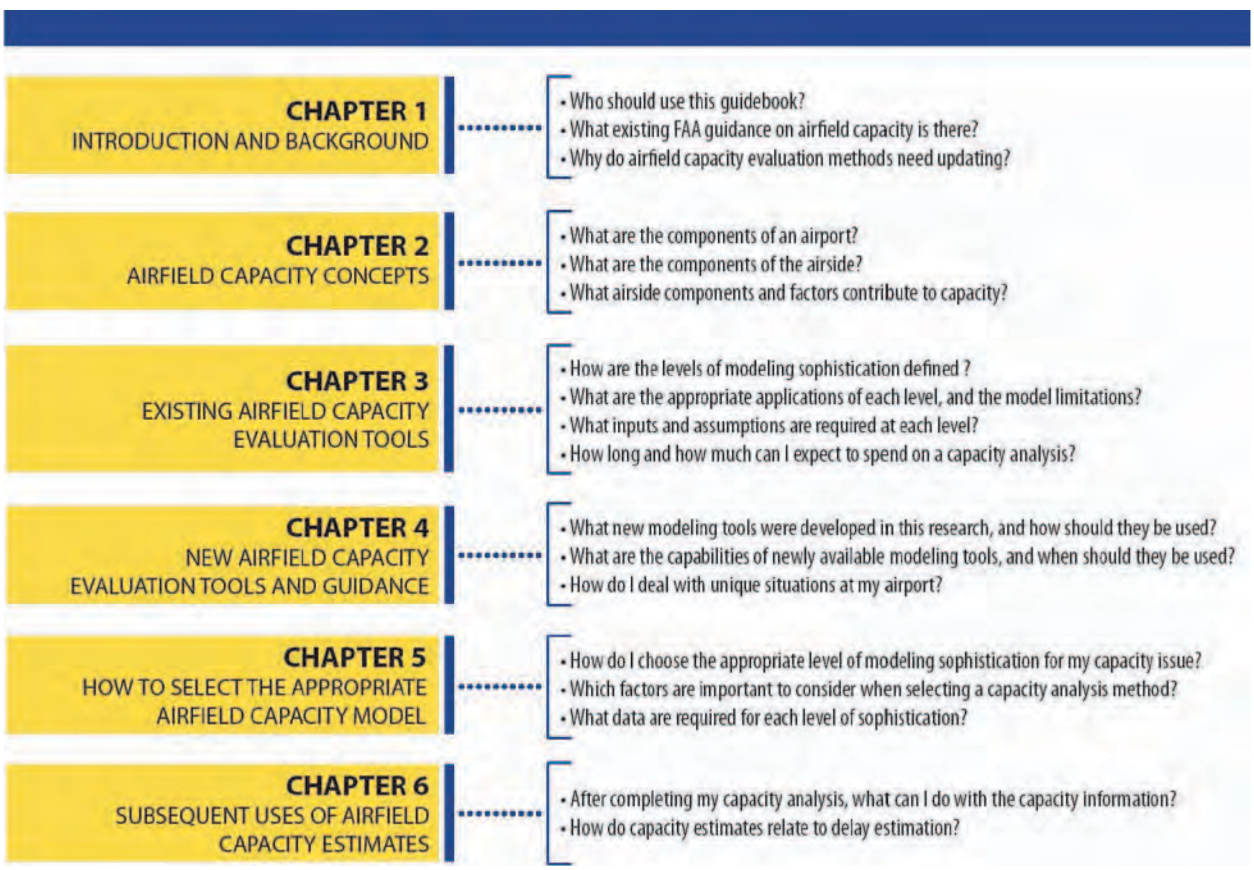


Figure 1-5. Overview of ACRP Report 79, including questions each chapter is intended to address.

- **Chapter 3, "Existing Airfield Capacity Evaluation Tools,"** describes the five levels of modeling sophistication identified in this research project. For each level, the applications; data requirements; model assumptions, inputs, outputs, and limitations; time, cost, and training requirements; model availability; model limitations and gaps; and other factors are presented.
- **Chapter 4, "New Airfield Capacity Evaluation Tools and Guidance,"** describes the new spreadsheet models developed for this research project, as well as other newly available tools. The chapter also includes a checklist that can be used in evaluating the various models and their applications.
- **Chapter 5, "How to Select the Appropriate Airfield Capacity Model,"** provides a decision-support tool that can be used in evaluating an airport's existing conditions relevant to selection of an appropriate level of modeling sophistication. Guidance also is provided on specialty capacity evaluations.
- **Chapter 6, "Subsequent Uses of Airfield Capacity Estimates,"** describes how the airfield capacity estimates can be used in estimating aircraft delay and references the ongoing ACRP 03-20 project, "Defining and Measuring Aircraft Delay and Airport Capacity Thresholds."

An Excel spreadsheet tool is provided on the attached CD-ROM, *ACRP CD-124.* The spreadsheet tool is described later in the guidebook, and a User's Guide for the tool is provided in Appendix A.

CHAPTER 2

Airfield Capacity Concepts

Airfield capacity is a function of the airport's physical facilities or components; its layout or geometry; its operating environment, including the airspace allocated to the airport and specific air traffic control (ATC) and flight procedures; the mix of aircraft using the airport; and weather conditions (i.e., ceiling, visibility, and winds). Understanding these factors, where to obtain information about them, and the required inputs and assumptions related to each factor, are all important prerequisites for analyzing airfield capacity.

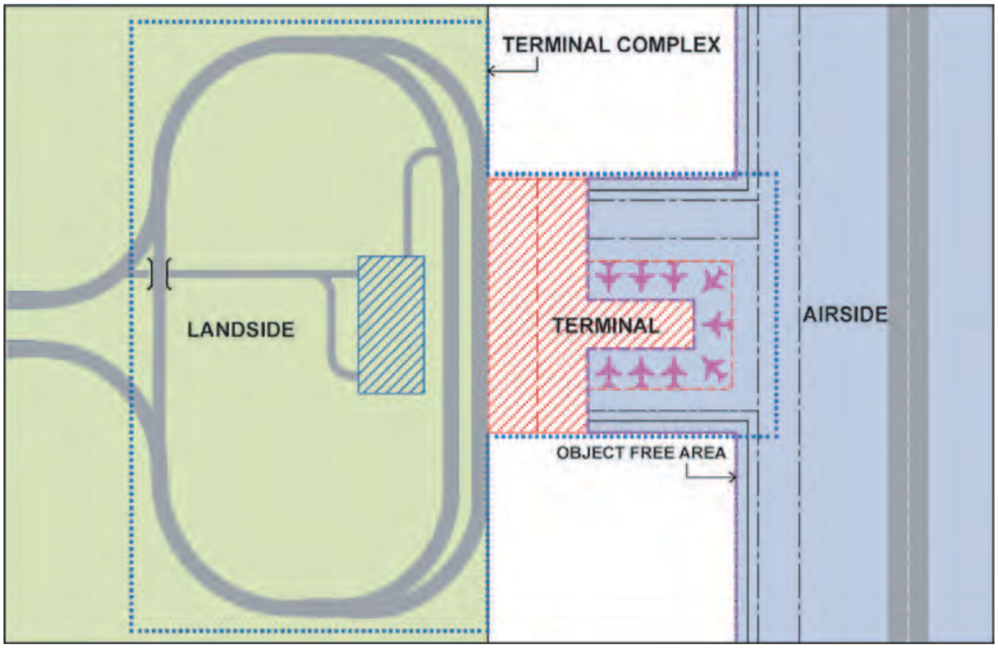
Airport Components

An airport encompasses many features that allow aircraft to take off and land and that allow pilots and passengers to access facilities on the ground. Typically, an airport's facilities are divided into three components: airside, terminal, and landside (Figure 2-1). These three components have specific functions and capacities, and their capacities must be in reasonable balance.

Airside facilities generally include those that support the transition of aircraft from air to ground or the movement of aircraft from parking or storage areas to departure and flight. The airfield itself is one component of the airside facilities, the dominant feature of an airport, and typically encompasses the largest land area. In general, the airfield includes the airport's runway and taxiway system; along with various aircraft hold pads or holding bays. Airside support facilities include airfield maintenance, marking and lighting, navigational aids, weather reporting stations, and ATC facilities. Airside facilities generally are common to all sizes of airports (every airport needs at least some type of runway), with varying degrees of complexity depending on the type and level of activity at the airport.

Terminal facilities are used to transfer passengers and aircraft crews from the landside to the door of the parked aircraft. Terminal facilities are provided at both commercial service and general aviation airports. The terminal itself is typically a passenger-processing building for ticketing and baggage claim, along with concourses and gates. Terminal facilities at commercial service airports usually are larger and have greater security, access, and general footprint requirements. Terminal building functions at general aviation airports are typically provided in a fixed base operator (FBO) building that houses a pilot's lounge, access to weather data, restrooms, and so forth.

Landside facilities provide the link between air and ground transportation. Landside facilities include airport access roadways, terminal area access and circulation roadways, terminal curbsides, automobile parking facilities, intermodal access, and commercial ground transportation staging facilities.



Source: Landrum & Brown.

Figure 2-1. Major airport components: airside, terminal, and landside facilities.

Airside Components Including Airfield Geometry

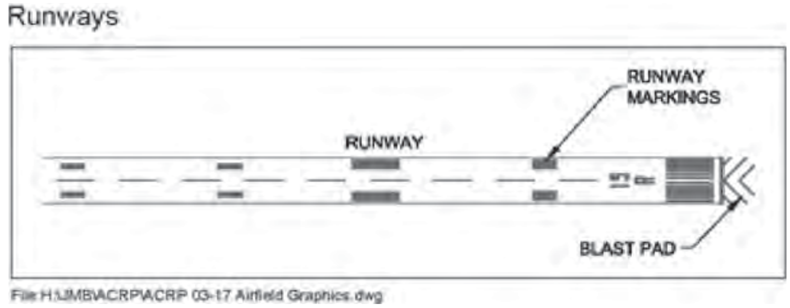
All of an airport's components—airside, landside, and terminal—work in conjunction with one another in operation of the airport. The airside components, including airfield geometry, are generally the limiting factor governing the ultimate capacity of the airport. As previously noted, airside facilities are designed to accommodate the movement of aircraft between final approach and aircraft parking for arrivals and from aircraft parking to initial climb-out for departures. At commercial service airports, these facilities usually are not accessible by the general public, but they are generally accessible to the public at smaller airports that do not have the same security and access requirements. Airside components include the following:

- Runways
- Taxiways
- Holding bays
- Aprons
- Gates

Runways

A runway is a strip of hard or paved level ground on which aircraft take off and land. A runway's surface typically is hard and can be made of concrete or asphalt as well as grass/turf, dirt, or gravel. At airports used mostly by commercial and larger general aviation aircraft, a concrete or asphalt runway is standard. Airports can have a single runway or multiple runways that may or may not be operated simultaneously. Figure 2-2 shows typical runway numbering and marking.

The number of runways and the way the runways are operated can have a substantial effect on airfield capacity. Runway length, width, pavement strength, and orientation determine whether a runway is usable by a particular aircraft type for landing or takeoff. The runway must be long enough for an aircraft to accelerate to takeoff speed or slow down sufficiently to exit the runway. The runway must be wide enough to accommodate the width of the landing gear and provide



Source: Landrum & Brown.

Figure 2-2. Runway numbering and marking.

wingtip clearance to adjacent buildings and aircraft. Runways are generally oriented in the direction of the prevailing winds; aircraft operate best with a headwind, and most aircraft have limited ability to fly with strong cross winds or tailwinds. Pavement must be strong enough to support the design aircraft (i.e., the largest aircraft regularly operating at the airport) without structural damage to the aircraft or pavement.

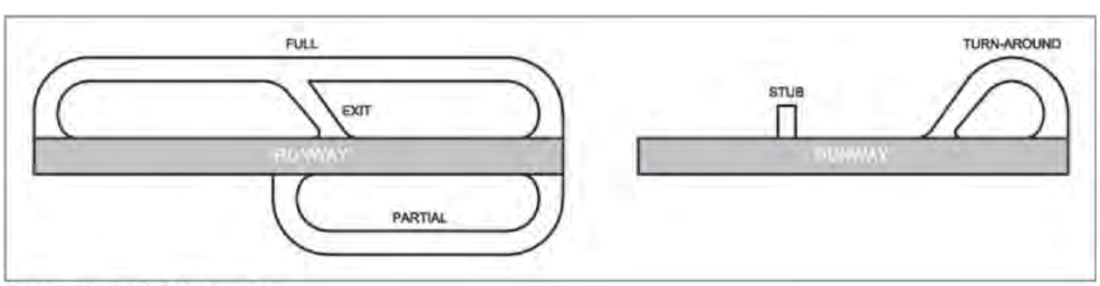
Taxiways

A taxiway is also a hard or paved strip of level ground along which aircraft taxi from the runway to a parking position (and vice versa) or from one part of the airport to another. Taxiways can be used to temporarily hold aircraft waiting to take off or waiting for a gate, but it is best to hold aircraft on an apron.

There are three major types of taxiways:

1. **Parallel (full or partial) taxiways,** which generally provide a route for aircraft to reach the runway end or to use after exiting the runway (see Figure 2-3)
2. **Entrance/exit taxiways,** which connect runways to parallel taxiways or some other type of taxiway, and which provide a path for aircraft to enter the runway for departure or exit the runway after landing
3. **Access (or circulation) taxiways,** which provide paths for aircraft to move between the various airside components of the airport (and which include bypass and crossover or transverse taxiways, including those that cross active runways, and apron-edge taxiways)

The number, location, and layout of taxiways can significantly affect airfield capacity. Taxiways provide space for the temporary staging and sequencing of aircraft prior to takeoff



Source: Landrum & Brown.

Figure 2-3. Taxiway types and locations.

and after landing. Such taxiway use frees the runways to be used efficiently for takeoffs and landings.

The combination of runways and taxiways is generally referred to as the *movement area.*

Holding Bays

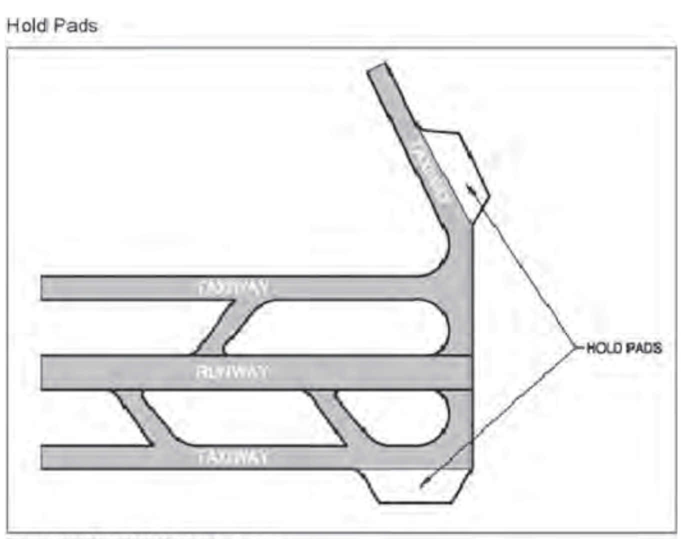
Located near the ends of runways or near the terminal building, holding bays (or hold pads) are intended to provide an area off the taxiway system for aircraft that must wait until ready to take off or until a gate is ready. Typical holding bay locations and geometries are shown on Figure 2-4. Holding bays can affect capacity if sufficient space does not exist for aircraft to wait without occupying a needed gate or blocking a taxiway.

Hold pads are provided primarily at busy commercial airports to stage and store aircraft awaiting departure so air traffic controllers can properly sequence them. *Deicing pads* are a special category of hold pads that are especially needed and important to airport operations during snow and ice conditions. Holding bays are useful, and in many situations necessary, near departure runway ends to allow aircraft to be bypassed for takeoff. Without this bypass capability, an aircraft holding for ATC clearance or because of inclement weather at its destination could unduly delay other departures attempting to use the same runway.

Holding bays also are necessary when, for a variety of reasons, a gate may not be immediately available for arriving aircraft. This type of holding bay should be located near the terminal complex to allow easy access to the gate area when a gate becomes available.

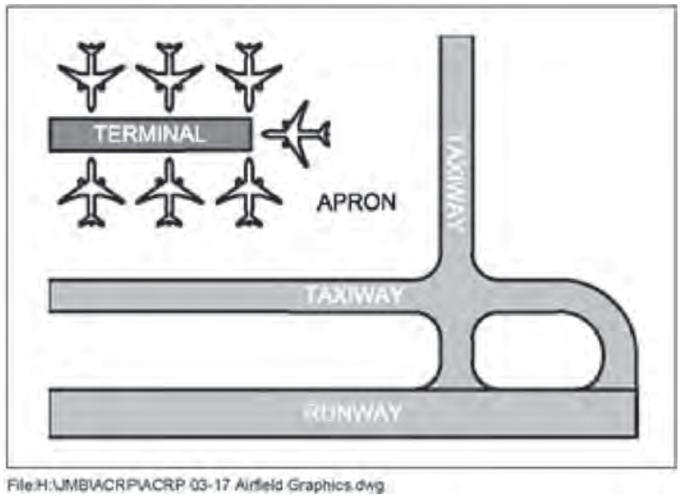
Aprons

Aprons typically are defined areas of land intended to accommodate parked aircraft for purposes of fueling, maintenance, or loading or unloading passengers, mail, or cargo (Figure 2-5 and Figure 2-6). Aprons typically surround buildings, such as terminals and hangars, but also can be designed specifically to store aircraft out in the open using tiedowns.



Source: Landrum & Brown.

Figure 2-4. Holding bays or hold pads at or near runway ends.



Source: Landrum & Brown.

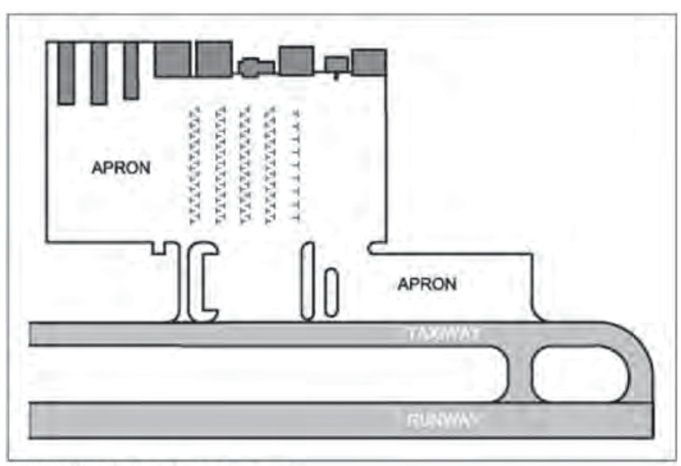
Figure 2-5. Commercial aircraft parking apron.

Large aprons can include taxilanes, which are areas identified to provide access between taxiways and aircraft parking positions. The combination of the apron and taxilanes is generally referred to as the *non-movement area.* At certain busy air carrier airports, spots are established as points on the apron where aircraft leaving a non-movement area are expected to contact ground control for taxi clearance.

Sometimes also referred to as the ramp, aprons at small general aviation airports are widely accessible, and both aircraft and automobiles may park on its surface.

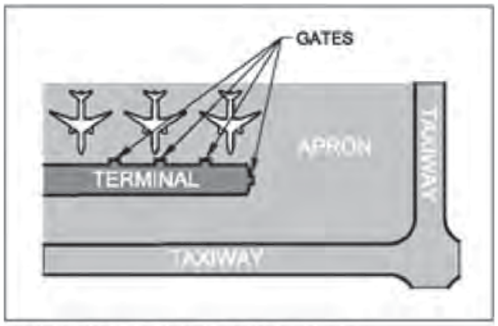
Gates

An airport's gates are the access points between the aircraft and the terminal at which passengers typically embark or disembark the aircraft (Figure 2-7). An airport can have one or more gates, and these gates may be at ground level or on an upper level, for which a loading bridge is provided to connect the aircraft to the door of the terminal building. At general aviation airports,



Source: Landrum & Brown.

Figure 2-6. General aviation parking apron (ramp).



Source: Landrum & Brown.

Figure 2-7. Terminal gates.

terminal entrance points are not typically called gates; this term is typically used at commercial service airports. Gates are designed to accommodate different types of aircraft and can affect capacity if the number of gates provided is inadequate to accommodate arriving or departing aircraft, or if the layout of gates impedes taxiing aircraft from reaching the runway ends in a safe and efficient manner.

Airport and Airspace Operating Environment

In addition to the ground-level physical layout and facilities, an airport's operating environment also includes the surrounding airspace. The structure and design of the airspace determine the number of routes that can be followed by aircraft flying into and out of the airport. Airspace constraints, such as high terrain, tall structures, special-use airspace, and aircraft operations at another nearby airport, may limit the number of such routes, thereby adversely affecting airfield capacity. Therefore, airspace is a very important consideration in evaluating airfield capacity.

Airspace is defined as the portion of the atmosphere above a certain land area. This land area can be defined in terms of the political subdivision that it overlays (e.g., the country or state), or it can be defined based on proximity to the airport. In the United States, FAA maintains and regulates civilian airspace to provide for a safe and efficient movement of air traffic. Aircraft flying in U.S. airspace are subject to a system of controls designed to serve one primary purpose—the safe separation of aircraft from one another and from other hazards. Such aircraft are subject to varying degrees of control depending on the specific airspace and meteorological conditions in which they operate. FAA is also responsible for the air traffic control system in the United States.

Two basic types of flight rules (or flights) are recognized in the U.S. air traffic control system:

1. **Visual flight rules (VFR).** Aircraft operating under VFR (VFR flights) depend primarily on the see-and-be-seen principle for separation. VFR flights are conducted primarily by smaller aircraft. FAA does not require pilots of VFR flights to file flight plans and—except for those services provided by FAA Flight Service Stations and local air traffic control towers (ATCTs)—such flights are not provided service (such as separation assurance and flight following) by the ATC system.
2. **Instrument flight rules (IFR).** Aircraft operating under IFR (IFR flights) are provided minimum radar separations by air traffic controllers. Pilots of IFR flights must file IFR flight plans to receive radar separation assurance and operate in certain controlled airspace. Pilots of large commercial flights nearly always file IFR flight plans and use instruments to navigate from point to point so they can fly in certain adverse weather conditions.

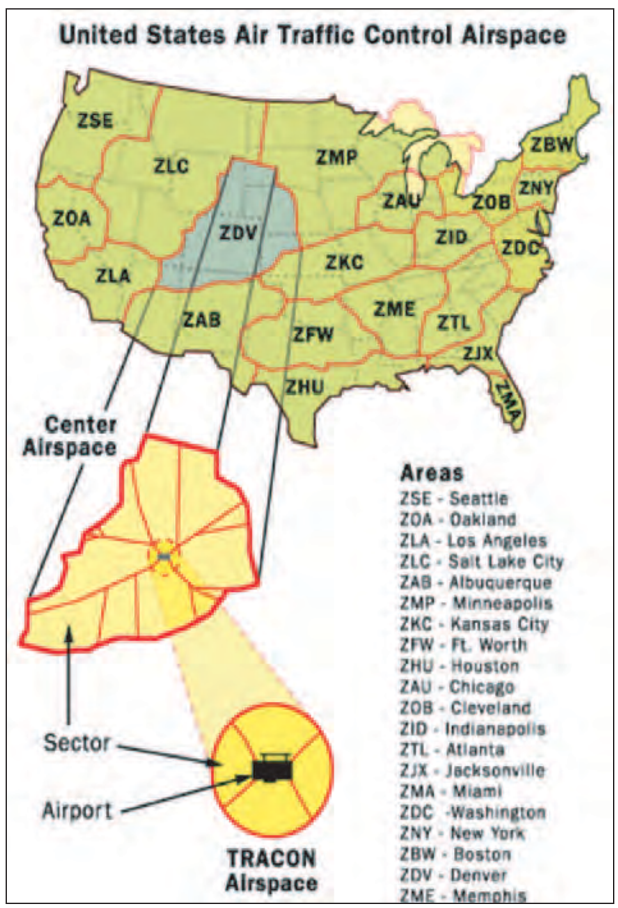
The National Airspace System (NAS) includes more than 19,000 airports, about 5,200 of which are open to the public; 400 ATCTs; 197 Terminal Radar Approach Control (TRACON) facilities; and 22 Air Route Traffic Control Centers (ARTCCs). Traffic management of the NAS is directed by the Air Traffic Control System Command Center (ATCSCC) located in Herndon, Virginia.

Control of air traffic within specific sub-areas of the NAS is delegated to one of the 22 ARTCCs that have specific jurisdiction. Each ARTCC is responsible for providing ATC services to a large segment of the NAS, which routinely involves dozens of airports and often encompasses all or part of a multistate area (Figure 2-8).

The ARTCC further delegates responsibility for air traffic management for smaller geographic areas within its boundary to TRACON facilities and ATCTs. The area of control exercised by the TRACON and ATCT is limited to a maximum defined altitude as well as a specified geographic area.

FAA Flight Service Stations provide pilot briefings and VFR search and rescue services, assist lost aircraft and aircraft in emergency situations, originate Notices to Airmen, broadcast aviation weather and NAS information, and receive and process IFR flight plans, among other services.

As an aircraft travels through a given airspace sector, it is monitored by one or more air traffic controllers responsible for that sector. As the aircraft leaves that airspace sector and enters



Source: Federal Aviation Administration.
Note: Not pictured: ZAN – Anchorage (Alaska), and ZHN – Honolulu (Hawaii).

Figure 2-8. FAA air route traffic control centers (ARTCCs).

another, the air traffic controller passes the aircraft off to controllers responsible for the other airspace sector.

Much of the current ATC system relies on ground-based navigational aids and radar. Radar—the acronym stands for **ra**dio **d**etection **a**nd **r**anging—depends on line of sight for detecting targets.

During instrument weather conditions, referred to as instrument meteorological conditions (IMC), approaching aircraft must be provided full radar separations by air traffic controllers until the pilots confirm that they can see their runway and the aircraft they are following, and certain movements may not be possible because of increased dependencies between runways (e.g., the operations on one runway may be dependent on operations on an adjacent runway in IMC when visual separation cannot be applied). IMC can result in significant reductions of airfield capacity.

During visual or clear weather conditions, referred to as visual meteorological conditions (VMC), approaching aircraft may be issued a visual approach by controllers, under which the pilot is responsible for aircraft separation (including wake turbulence separation) and can visually follow the aircraft in front to the runway. Moreover, in VMC, there is less dependence between runways and air traffic controllers in the ATCT can apply visual separations between aircraft, which can result in a significant increase in airfield capacity.

Marginal VMC (MVMC) conditions are defined as ceiling and visibility conditions below visual approach minimums, but better than instrument conditions. Under MVMC, conducting visual approaches is either not possible or requires additional controller workload; however, the full radar separations do not need to be enforced once the pilot has the airport or the preceding aircraft in sight.

FAA establishes airspace classes to enhance the safety of aircraft operations by protecting arriving and departing IFR aircraft using ATC services from uncontrolled VFR aircraft.

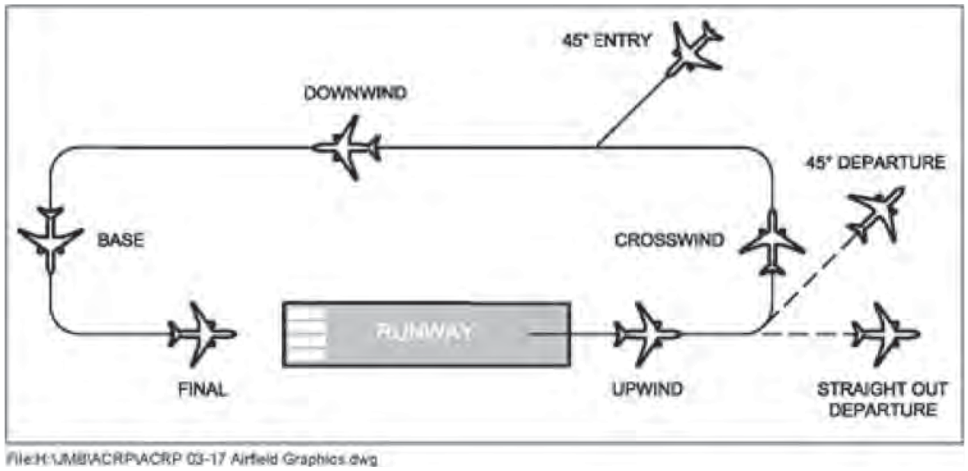
Depending on the class of airspace, VFR operations are subject to certain operational restrictions and, when operating in certain restricted classes of airspace, must remain under controller/radar communications and surveillance at all times. These airspace-class restrictions most often affect general aviation users because general aviation aircraft flights account for the majority of VFR traffic.

Training activity at an airport is of particular note for airspace and general airport operations as it relates to determining airfield capacity. Training operations, also called touch-and-goes, are defined by how the aircraft perform. In a touch-and-go operation, aircraft make a landing followed by an immediate takeoff without coming to a full stop or exiting the runway. Each aircraft that conducts a touch-and-go accounts for two operations (a landing and a takeoff) even though the operations are conducted in rapid succession. Airports that have a high level of touch-and-go activity can accommodate a high number of operations.

If the pilot brings the aircraft to a full stop before taking off again, it is called as a stop-and-go operation. Stop-and-go operations can have a significantly longer runway occupancy time and therefore can adversely affect the number of operations that an airport can accommodate.

Training operations also affect an airport's *traffic pattern,* which is the standard path followed by aircraft when taking off or landing while maintaining visual contact with the airfield (Figure 2-9). A traffic pattern is established to be used by aircraft that remain close to the airport, including training aircraft, and is more commonly used by general aviation aircraft and at smaller airports.

Traffic patterns also are defined for all sizes of airports for purposes of aborted or missed approaches, but these patterns may not follow the same path as that used for training or local operations at an airport. Traffic patterns are defined as left-hand or right-hand according to the



Source: Federal Aviation Administration.

Figure 2-9. Traffic pattern operating segments and procedures.

direction in which they are flown. Left-hand patterns are standard, because most small aircraft are piloted from the left seat; but right-hand patterns are used frequently for other reasons (e.g., to accommodate parallel runways, for noise abatement, and to manage terrain issues). Traffic patterns are usually rectangular in shape, with the runway serving as one of the long sides of the rectangle.

When training operations begin to affect the ability of the airport to efficiently accommodate aircraft traffic due to too many aircraft in the traffic pattern, air traffic controllers may ask pilots to conduct full-stop landings instead of touch-and-goes or stop-and-goes. With full-stop landings, the training aircraft land and exit the runway to stop and wait on an approved taxiway or apron until cleared to re-enter the runway for another takeoff. Switching to full-stop landings thus reduces the number of aircraft active in the traffic pattern.

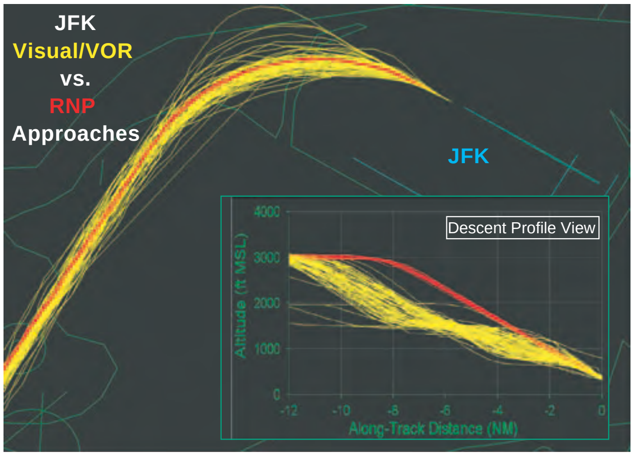
Next Generation Air Transportation System (NextGen)

NextGen is the umbrella term used in the industry to describe the ongoing, wide-ranging transformation of the NAS. The transformation is focused on changing the legacy, radar-based ATC system and the legacy, ground-based navigation system to satellite-based systems. As proposed, the satellite-based technologies are expected to significantly improve the safety, capacity, and efficiency of runways in the NAS while providing environmentally friendly air traffic procedures and technologies that reduce fuel burn, carbon emissions, and noise.

NextGen is a collaborative effort among FAA and partners from the airlines, the Aerospace Industries Association, federal agencies, airports, and state and local governments. NextGen is part of a worldwide effort to modernize ATC systems, and FAA is collaborating with other air traffic service providers to ensure that future communications, navigation, and surveillance technologies and procedures are harmonized and interoperable internationally.

One of the most important technologies behind NextGen is the global positioning system (GPS), an application that has been used in aircraft approach procedures to airports of all sizes.

Through the use of new navigation procedures, such as Area Navigation (RNAV) and Required Navigational Performance (RNP)—illustrated in Figure 2-10—aircraft will be capable of flying more direct and narrowly defined routes, even during inclement weather conditions, allowing the possibility for the airport to be operated with reduced separation standards, thereby increasing airfield capacity.



Source: Federal Aviation Administration.

Figure 2-10. Potential RNP approach versus existing VOR approach: plan and profile.

While the primary emphasis of NextGen is on safety and efficiency, the potential improvements in airfield capacity are significant. Airfield capacity improvements are anticipated as more precise surveillance, navigation, and controller automation tools reduce effective separation between aircraft. Separation buffers built into today's operations will be reduced so that aircraft can achieve average separations closer to published minimum standards.

For airports with parallel runway systems, the required separation between the runways is expected to be reduced, which would allow greater flexibility for designing additional runways and adding capacity to existing parallel runways that meet the reduced standards. Collaborative decision making in airport surface management improves departure sequencing and taxiing efficiency.

Other innovations are ongoing in areas such as weather forecasting, data networking, and digital communications. In addition to technological changes, new airport infrastructure, new and renovated aircraft fleets (including advanced engines and airframes), and new aircraft approach and departure procedures will be part of NextGen implementation.

NextGen has been discussed for many years, and some of the technologies, standards, and procedures have already been implemented; the gradual evolution of the NAS is under way and will continue for many years.

Aircraft Fleet Mix and Performance Measures

Aircraft fleet mix refers to the size, engine power (i.e., piston, turboprop, or jet), wake turbulence category, and performance (e.g., approach speeds and runway occupancy times) of all aircraft types operating at an airport. The fleet mix is a core parameter that affects every capacity analysis with respect to the following considerations:

1. **Aircraft separation criteria.** Separation requirements between arrivals and departures are enforced through ATC rules and procedures, which are typically based on an aircraft's maximum gross takeoff weight capability. Aircraft wings generate lift, a byproduct of which is wake turbulence. Separation requirements vary depending on the difference in size between the leading aircraft and the trailing aircraft, with larger separations required behind heavier aircraft to protect for wake turbulence. Figure 2-11 illustrates the wake vortices that come off

Source: Federal Aviation Administration.

Figure 2-11. Extra separation is required to protect for wake turbulence.

the tips of the aircraft wing and trail behind the aircraft, creating a danger for smaller aircraft that might be caught in the wake. Behind large aircraft, these wake vortices can be very strong, and controllers must build in extra separation to protect against a dangerous wake encounter.

Two other determinants of aircraft separation criteria are airport surveillance radar and aircraft navigation precision. How precisely an aircraft's position is known to ATC, and how precisely an aircraft is able to follow a path through airspace both drive the need for separation requirements, particularly in instrument weather conditions.

2. **Runway use restrictions.** The use of a runway may be restricted depending on the operating requirements of an aircraft type or runway use preferences at an airport. For example, certain runways may be designated for smaller aircraft or non-jet aircraft for noise abatement purposes. In addition, runway length requirements may preclude certain runways from being used by larger aircraft or may dictate a preferred mode of operation for certain classes of aircraft.
3. **Final approach speeds.** An aircraft's size, weight, and engine power determine its typical speed on final approach. Final approach speed affects airfield capacity because higher approach speeds allow higher throughput rates; however, airfield capacity can be adversely affected when there are significant differences in final approach speeds of aircraft in the fleet for which controllers must provide protection from loss of separation.

The typical aircraft classification system depicted in Table 2-1 is included in this guidebook as it relates to evaluating airfield capacity. The specific aircraft mix categories appropriate for an airfield capacity analysis may differ from airport to airport. Refer to Appendix A and Appendix B of FAA Order JO 7110.65, *Air Traffic Control,* for current aircraft classifications.

All B-757 aircraft models were reclassified in 2010 as large aircraft, but the B-757 still requires special wake turbulence separation criteria that place it in its own aircraft class.

Other Factors That Affect Airfield Capacity

The airport, airspace, and aircraft considerations discussed in this chapter all affect airfield capacity. In each of these categories, specific characteristics have a greater or lesser effect and, therefore, require proportionate consideration in the calculation of airfield capacity. The following four important factors can have a significant effect on airfield capacity:

Table 2-1. Aircraft classifications.

Aircraft Class	Description	Maximum Gross Takeoff Weight	Sample Aircraft
Small-S	Single engine	Less than 12,500 pounds	Cessna 172, Piper Warrior
Small-T	Twin engine	Less than 12,500 pounds	Beach 35, Piper Seneca, Turbo Commander
Small +	Mixed engines	Between 12,500 pounds and 41,000 pounds	Lear 35, Hawker 400, Citation 10
Large	Multiple engines	Between 41,000 pounds and 300,000 pounds	B-737, A319, Global Express, CRJ-200
B-757	Boeing 757	300,000 pounds	B-757
Heavy	Multiple engines	More than 300,000 pounds	B-747, B-767, B-777, A330
Super Heavy	A380	1,200,000 pounds	A380

Source: FAA Order 7110.65, *Air Traffic Control*.

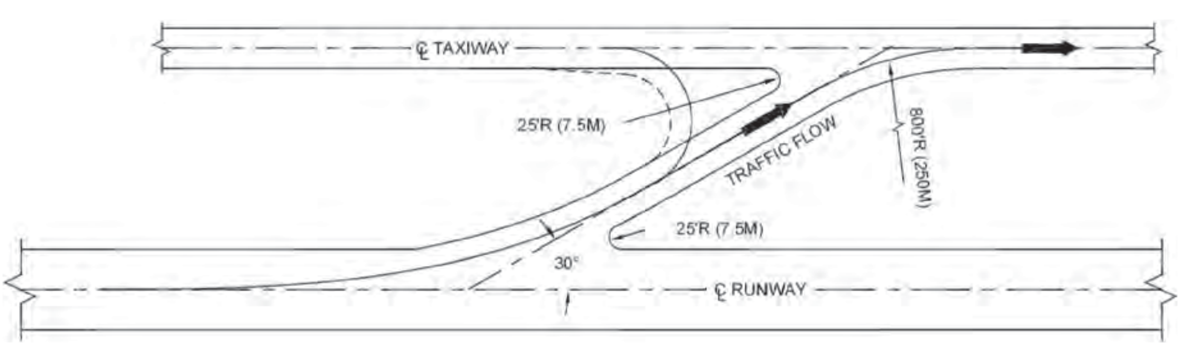
1. Airfield geometry
2. Aircraft mix, activity type, and scheduling
3. Weather, runway use, and ATC procedures
4. Airspace

Airfield Geometry Factors

Runway Exit Design

Runway exit taxiways are most important during periods of mixed mode operations on a single runway, allowing arriving aircraft to exit the runway as quickly as possible and increasing the likelihood that a departure will have time to take off before the next arrival occupies the runway, thereby increasing runway capacity. However, even on a runway used for arrivals only or departures only, runway occupancy times can limit airfield capacity.

Runway exits that have a shallow angle to the runway centerline allow an aircraft to exit the runway at a higher speed than those with larger angles to the runway centerline. The standard geometry for a high-speed exit is shown in Figure 2-12. In cases where the centerline separation between a runway and parallel taxiway is insufficient to allow full high-speed exits, acute-angle exits can be used. Acute-angle exits are not true high-speed exits but allow aircraft to



Source: Federal Aviation Administration.

Figure 2-12. FAA standard high-speed runway exit geometry.

exit at nearly the same speeds. Usually an aircraft will need to slow down on a runway to use a 90-degree or reverse-angle exit, thereby taking more time on the runway and reducing airfield capacity.

A landing aircraft exiting the runway at a higher speed reduces runway occupancy time, allowing the runway to be used by other aircraft more efficiently.

Runway Entrance Design/Departure Staging and Sequencing Taxiways

Having more than one entrance taxiway to a runway or holding bay may increase runway capacity. A secondary entrance taxiway may enable an intersection departure, allowing a departing aircraft to use only the portion of a runway that does not intersect with another runway rather than the full length of the runway. Additionally, multiple runway entry points or a holding bay at the departure end of a runway could allow flexibility for air traffic controllers to optimize the sequence of departing aircraft or remove aircraft from the queue before they reach the runway end if they have a mechanical problem or are awaiting takeoff clearance.

Parallel Taxiway

A parallel taxiway allows departing aircraft to reach a runway entrance without taxiing on the runway and can keep arriving aircraft from having to back-taxi on the runway to access the ramp if they roll past the last runway exit. The length of the parallel taxiway (full or partial) can affect airfield capacity. The efficiency of a partial parallel taxiway depends on its length and location in conjunction with the direction of departing or landing aircraft. The lack of a full-length parallel taxiway may greatly increase runway occupancy time for arrivals and departures, thereby reducing airfield capacity.

Runway Crossings

Aircraft taxiing across an active runway impede the runway's primary purpose of providing a space for landing and departing aircraft. Crossing aircraft also divert ATC resources from the task of controlling landing and departing aircraft. Large gaps may sometimes occur in the operations on a particular runway (e.g., due to a large wake turbulence separation behind a heavy jet aircraft). Such large gaps may permit one or two aircraft to cross the runway; however, gaps that are not large enough to permit such crossings will reduce the time available for the runway to be used for landings and takeoffs. Providing multiple runway crossing points may mitigate the adverse effect of runway crossings.

Number of Runways and Relative Location

Airports provide varying numbers of runways to accommodate aircraft operations. These runways can have a variety of configurations depending on conditions at the airport, when the runways were constructed, and other factors. A single-runway airport can accommodate a high level of aircraft operations depending on the availability of other infrastructure, such as instrumentation and taxiways, as well as operating conditions. Two or more runways can provide increased capacity compared with a single runway, but it depends on the runway configuration and layout (i.e., runway lengths, separation between runway centerlines, and whether the runways are parallel, intersecting, converging, or otherwise dependent).

Aircraft Mix, Activity Type, and Scheduling Factors

Aircraft Fleet Mix and Approach Speeds

As previously discussed, aircraft fleet mix includes the size, engine power, performance, and wake turbulence of the aircraft types serving the airport. A significant mixture of different air-

Table 2-2. Aircraft approach speed categories.

Aircraft Category	Approach Speed	Example
A	< 91 knots	Cessna 172
B	91 to < 121 knots	King Air 200
C	121 to < 141 knots	B-737
D	141 to < 166 knots	B-767
E	166 knots or more	SR-71

Source: FAA Advisory Circular AC 150/5300-13*, Airport Design*.

craft types operating on the same runway can significantly affect the capacity of an airfield: the greater the differences in aircraft performance and wake turbulence categories, the greater the adverse effect on capacity.

The size, engine power, and weight of an aircraft also affect its approach speed for landing. Approach speed varies and is expressed by FAA using the letters A through E. Table 2-2 lists aircraft approach speed categories.

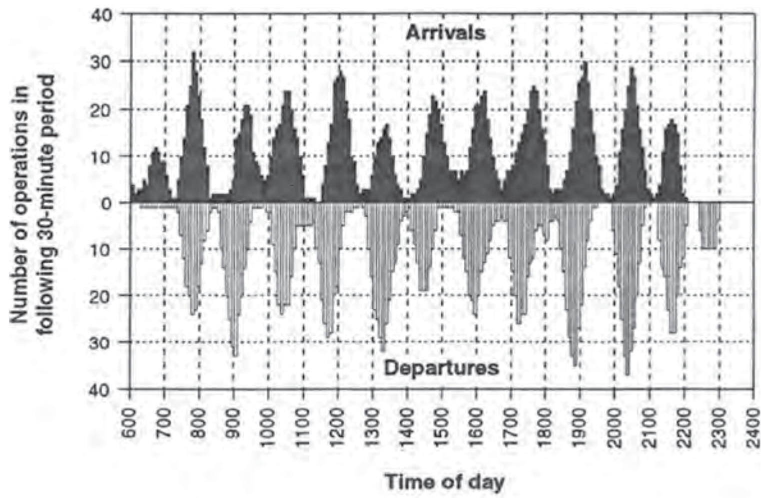
Activity Type

Commercial passenger service can affect airfield capacity depending on the types of aircraft that provide the service and the number of operations conducted by the commercial passenger airline(s). If the passenger service is provided with larger aircraft, the capacity calculations are affected to a greater degree than if the size of the aircraft is more homogeneous. The presence of touch-and-go training activity is also an important consideration. Touch-and-go operations typically increase the runway operational throughput that can occur in an hour because aircraft land, followed by an immediate takeoff without coming to a full stop or exiting the runway, and therefore have shorter runway occupancy times. Airports that have a high proportion of touch-and-go activity can accommodate a high number of landings and takeoffs for a given capacity and set of assumptions regarding aircraft separations, approach speeds, runway occupancy times, and fleet mix. By contrast, a stop-and-go operation, where a pilot comes to a full stop on the runway and then takes off, can significantly increase runway occupancy time and reduce actual throughput.

Daily Distribution of Aircraft Activity/Detailed Flight Schedules

Aircraft activity scheduling patterns also can influence airfield capacity, depending on how capacity is defined. When capacity is defined as a function of average aircraft delay, it is affected by the demand peaking patterns at the airport. When capacity is defined in terms of annual service volume, then it is also a function of the demand peaking distribution and the seasonality of traffic at the airport.

At small commercial and general aviation airports, traffic tends to peak in the morning and at night, sometimes influenced by weather or air traffic. The presence of pilot training, typically at smaller commercial or general aviation airports, can also result in scheduling that affects capacity. At large airports, airlines may group arriving or departing aircraft to promote passenger connections. This practice is often called *hubbing.* Hubbing creates unique stresses on airfield capacity because a comparatively large number of aircraft are attempting the same activity nearly simultaneously (see Figure 2-13).



Source: Official Airline Guide for Lambert St. Louis International Airport.

Figure 2-13. Demand pattern showing peak arrival and departure banks at major connecting hub.

Long distance flights also affect airfield capacity as airlines schedule flights when passengers demand them. Most passengers generally do not want flights that arrive or depart in the middle of the night. International flights in particular need to meet airline hubbing windows for airline connection efficiency, making the windows for their arrival or departure particularly narrow.

For commercial service airports with high levels of aircraft activity, detailed flight schedules can be used in the capacity calculation. These schedules, which can be purchased through commercial vendors, provide aircraft type, airline, time of day, and other relevant information critical to capacity evaluations.

Weather, Runway Use, and ATC Procedural Factors

Weather

Weather conditions affect runway use, runway orientation, and aircraft separation requirements. Wind speed and direction determine aircraft speed over the ground during flight (i.e., the aircraft's ground speed). Wind speed variability (gusts) may cause a pilot to increase speed. Higher approach or departure speeds generally increase runway length requirements. In addition, strong winds can limit the runway orientations that can be used at any given time, which may limit an airport with multiple runway orientations to a single orientation and a reduced airfield capacity.

Cloud ceiling and visibility at the airport, which define whether aircraft are operating in VMC, MVMC, or IMC, also affect airfield capacity. These weather categories are typically defined by FAA as follows:

- **VMC:** Ceiling and visibility allow for visual approaches. Visual approach minima, expressed as a combination of ceiling and visibility, are specific to each airport.
- **MVMC:** Ceiling and visibility are below visual approach minima but better than instrument conditions.
- **IMC:** Ceiling less than 1,000 feet or visibility less than 3 statute miles. Under these conditions, instrument flight rules apply and radar separation between aircraft is required.

These distinctions are important because, assuming all other factors are equal, fewer aircraft operations can occur when visual approaches are not conducted and aircraft require additional separation from one another. For example, in IMC, controllers can no longer apply visual separation from the ATCT or direct pilots to conduct visual approaches to the airport's runways; instead, full radar separations must be applied. Moreover, increased dependencies between runways in IMC may limit the number of simultaneous movements that can occur at the airport. In IMC, there are stricter requirements on pilot and aircraft certifications and performance capabilities than in VMC, which may affect the number of pilots that can fly in poor weather conditions.

Applicability and Acceptance of VFR and Visual Approaches/ Separation Standards (Arrivals and Departures)

Airfield capacity is usually higher in VMC, when pilots accept responsibility for self-separation from other aircraft traffic through see-and-avoid techniques. In IMC, air traffic controllers separate aircraft by applying standard minimum radar separation distances. Because of the variability of weather conditions, controllers will add an additional separation buffer to assure that minimum separation distance standards are not violated.

In addition, pilot acceptance of visual approaches depends on the pilot's level of proficiency with the English language and the use of voice communications to understand the location of nearby aircraft traffic. If visual approaches are being accepted by the majority of pilots operating at an airport, then airfield capacity can be significantly increased. During periods of IMC, controllers are able to handle fewer aircraft operations at an airport because they must provide full radar separations and apply minimum separation and divergence requirements between arriving and departing aircraft.

Runway Occupancy Time

Runway occupancy time refers to the time interval that an aircraft occupies a runway. This time interval is usually expressed in seconds. For arrivals, runway occupancy time refers to the time an arriving aircraft takes between crossing the runway threshold until it is clear of the runway, meaning it is outside the Runway Safety Area (RSA). For departures, runway occupancy time refers to the time a departing aircraft takes from the moment it occupies an active runway, meaning the time it enters the RSA, until it clears the departure end.

Multiple-Approach and Departure Capability

Multiple-approach airspace design extends final approach and departure corridors, which tends to magnify the negative effects of aircraft speed variations on individual runway acceptance rates. (A similar effect occurs on multiple parallel or diverging departure runways.)

Alternatively, approach procedures for closely spaced parallel runways (i.e., Simultaneous Offset Instrument Approach, or SOIA) and converging/intersecting runways (i.e., Convergence Runway Display Aid, or CRDA) can increase airfield capacity, especially in poor weather conditions.

Table 2-3 summarizes the minimum spacing requirements between parallel runways and associated operational capabilities and requirements. For more information regarding these requirements, please refer to FAA Order JO 7110.65, *Air Traffic Control.*

Fleet-Mix-Specific Runway Assignment

A runway can be limited by the types of aircraft that are able to use it. Factors such as airplane design group, runway length, or noise restrictions may cause the aircraft fleet mix that can use a

Table 2-3. Required parallel runway spacing for multiple approaches and departures.

Spacing Between Parallel Runways	Enabled Procedures and Requirements
Very close (700 feet to 2,500 feet)	Independent visual approaches in VMC with wake turbulence avoidance procedures Single stream in IMC
Close (2,500 feet to 3,000/3,400/4,300 feet)	Dependent (staggered--1.5 nautical miles) instrument landing system (ILS) approaches Independent departures Independent arrivals and departures
Far (greater than 3,000/3,400/4,300 feet)	Dual simultaneous independent ILS approaches 3,000 feet -4,300 feet requires Precision Runway Monitor (PRM) 3,000 feet -3,400 feet requires that one localizer be offset 2.5 degrees
Far (greater than 5,000 feet)	Triple simultaneous ILS approaches
Widely spaced (9,000 feet+)	Simultaneous ILS approaches without final monitors/No Transgression Zone

Source: FAA Order JO 7110.65, *Air Traffic Control,* 2012, and FAA Notice JO 7210.33, *Simultaneous Widely Spaced Parallel Operations*, 2012.

particular runway to differ from the overall fleet mix serving the airport. Limitations on aircraft types able to use a particular runway can have negative effects on airfield capacity. For example, if only a small percentage of the aircraft fleet mix can use a particular runway, then that runway's contribution to the overall airfield capacity is also small.

Radar Availability

The availability of en route or airport surveillance radar can significantly affect airfield capacity, especially for IFR flights in IMC. In the absence of such radar coverage, the air traffic controllers cannot use radar separations for arriving or departing aircraft. At such airports, procedural separation (e.g., the one-in, one-out rule) is used instead of radar separation, or time-based separation requirements (e.g., 10 minutes between successive arrivals) can be used, which can be many times larger than the minimum radar separation requirements.

ATCT Availability

The effect on airfield capacity of having an operating ATCT in VMC depends on the nature of the traffic and the makeup of the pilot population at an airport. At some uncontrolled airports that are well equipped with a Common Traffic Advisory Frequency (CTAF)—which might take the form of a UNICOM or MULTICOM radio frequency over which pilots can transmit and receive advisories–the absence of an ATCT could increase capacity, because there is nothing to enforce aircraft separation standards. At other airports that are not equipped for pilots to announce their intentions or to receive airport advisories, an ATCT could increase capacity by providing for a more orderly flow of traffic.

Under IMC, the capacity of an uncontrolled airport to accommodate instrument approaches and departures is severely limited. Capacity can be even further reduced if there is a lack of radar coverage.

As traffic levels rise and operational complexity increases, an ATCT could become warranted under FAA guidelines in order to foster the safe and efficient flow of traffic.

Airspace Factors

Length of Common Final Approach

There are varying types of approaches to an airport's runways. The length of the common approach is the distance from the runway threshold out to the entry gate of the outer boundary, where aircraft operating at different approach speeds may open or close the gap between them during final approach. More specifically, the common final approach path is that link over which controllers can no longer apply speed control or vectoring to adjust the separation between aircraft. Over that final distance to the runway, aircraft are flying at their certificated final approach speeds, which cannot be significantly changed. Therefore, differences in those final approach speeds must be accounted for in separating aircraft. This is particularly important when an overtake situation exists—where a faster aircraft is following a slower aircraft on final approach—and controllers must build in extra separation to counter the loss of separation. Such speed differences also have to be accounted for in situations where departures have to follow the same path after takeoff for a significant distance.

Buffers

Buffers are used to space aircraft in excess of the minimum required separation during various phases of flight, including arrivals and departures, to ensure that separation is not lost, which could result in an operational error. A spacing buffer, typically presented in seconds, is used to manually space arriving aircraft to balance the arrival and departure mix and allow for more departures between arrivals. A departure hold buffer is applied to departure runway occupancy times or the suggested minimum time between departures and is added as an additional time requirement before a departure can be initiated. An arrival hold is similar, but is typically presented in nautical miles. Additionally, minimum separation requirements also have buffers to reflect controllers' tendencies to add spacing beyond that required between operations to avoid operational errors. These separation buffers have been measured many times at various locations, and are well understood. They are primarily a function of the capability of the controller to sequence and space aircraft on final approach, which is a function of the technologies that the controller has available for such sequencing.

Departure Fix Restrictions

A departing aircraft flies through a series of waypoints, or fixes, to an arrival runway. These waypoints are generally where flight paths from multiple airports merge, or where an airport departure route merges with an overhead flight route or corridor. If there are too many flights en route to a fix, air traffic controllers may restrict the flow of traffic from an airport by assigning a minimum distance or time interval between successive departures. These restrictions are referred to as miles-in-trail or minutes-in-trail restrictions, respectively. The adverse effects of these in-trail departure fix restrictions can be mitigated by providing adequate bypass taxiways and holding bays on the airfield so that controllers can properly stage and sequence departures to minimize the incidents where successive departures are flying to the same fix.

Availability of Multiple Divergent Departure Headings

On departure, aircraft are assigned initial heading. To allow successive or simultaneous departures from parallel runways, the initial separation between headings must meet certain divergence requirements (e.g., a divergence of 15°) described in FAA Order JO 7110.65. The provision of divergent headings is a key factor to determining an airport's departure capacity.

Neighboring Airports

A runway needs adjacent airspace to accommodate the approach paths that feed it and the departure paths that flow from it. In some cases, airports are so close together that these

Source: LeighFisher.

Figure 2-14. Airspace interactions between JFK and LGA.

approach and departure paths cannot be operated simultaneously and must be shared (see Figure 2-14). When this occurs, air traffic controllers must coordinate the runway use configurations and air traffic flight paths between the two airports. Such coordination of air traffic at two or more nearby airports usually results in a substantial loss of efficiency and a reduction in airfield capacity.

CHAPTER 3

Existing Airfield Capacity Evaluation Tools

The purpose of this chapter is to identify the various levels of current modeling sophistication for analyzing airfield capacity and to describe typical examples and features of each level.

Although they are out-of-date, FAA's AC 150/5060-5, *Airport Capacity and Delay* (the AC), and Airfield Capacity Model (the ACM) provide a useful starting point for discussing the levels of modeling sophistication. The four levels implied in the AC are as follows:

1. **Table Lookup,** as illustrated in Chapter 2, "Capacity and Delay Calculations for Long Range Planning," in the AC
2. **Charts, Nomographs, and Spreadsheets,** as illustrated in Chapter 3, "Airport Capacity and Aircraft Delay Calculations," in the AC and new spreadsheets presented in Chapter 4 of this guidebook
3. **Analytical Capacity and Delay Models,** as described in Chapter 5, "Computer Programs for Airport Capacity and Aircraft Delay," of the AC these models are computer programs for calculating airfield capacity and aircraft delay as described in Chapter 3 of the AC.
4. **Airfield Simulation Models,** as described in Chapter 5 of the AC, are computer programs that include models such as the FAA Airport and Airspace Simulation Model (SIMMOD), the FAA Airfield Delay Simulation Model (ADSIM), and proprietary software.

ACRP Report 79 focuses on the first three levels of modeling sophistication plus a fifth level identified by this project's research and illustrated by the MITRE Corporation's *runway*Simulator. The *runway*Simulator differs from earlier models like SIMMOD, ADSIM, and the Total Airspace and Airport Modeler (TAAM)—and even from runways-only simulation models such as FAA's Runway Delay Simulation Model (RDSIM)—in that it has been designed to produce estimates of airfield capacities (maximum sustainable throughputs) rather than aircraft delays, although it can be used to estimate both. As such, the MITRE model is likely to be less intensive in relation to data and workload and therefore will likely require fewer resources to apply than the conventional airfield simulation models.

Table 3-1 presents information about the five levels of modeling sophistication discussed in this guidebook. The range of modeling analyses and techniques presented in Table 3-1 should provide airport operators and airfield capacity analysts with appropriate levels of sophistication to address the wide range of capacity analyses issues they are likely to encounter. Identification of a new level of sophistication (airfield-throughput simulation models) fills in an important gap between the analytical models and the simulation models.

The five levels of modeling sophistication are further described in the remaining sections of this chapter, with respect to the following characteristics:

- **Applications:** Typical capacity issues that can be analyzed with the level of modeling sophistication (i.e., what is this level of modeling sophistication best suited to do?)

Table 3-1. Proposed levels of modeling sophistication.

Level	Description	Examples	Sample Applications	Attributes/Limitations	Data Requirements
1	Table lookup	Chapter 2 of the AC, new lookup table	Statewide system plans, airport master plans where airfield capacity is not an issue, and small airport master plans	Runways only, simplified airfields, small airports, default assumptions only	Minimal, requiring only an overview of airport runway configuration and aircraft fleet mix
2	Charts, nomographs, and spreadsheets	Chapter 3 of the AC, new spreadsheet model	Statewide system plans, airport master plans where airfield capacity is not an issue, and small airport master plans	Runways only, moderate size airports, less complex airfields, some flexibility in inputs	Minor, requiring airport runway configuration, aircraft fleet mix, exit locations, and percentage of arrivals
3	Analytical capacity models	Airfield Capacity Model	Specialized airfield capacity studies, airport master planning studies, regional airport system planning	Runways only, moderate airfield complexity, taxiways and airspace considered implicitly, flexible input assumptions	More demanding, including aircraft fleet mix, aircraft final approach speeds, aircraft separations, and air traffic control (ATC) rules
4	Airfield capacity simulation models	*runway*Simulator, Flexible Airport Simulation (FLAPS)	Capacity planning of complex airfields or regional airfield/ airspace systems	Runways only, complex airfields and airspace, flexible assumptions	More detailed input data than Level 3 models, including close-in arrival and departure flight track geometries and aircraft fleet mix by runway
5	Aircraft delay simulation models	SIMMOD, ADSIM, TAAM	Detailed planning of complex airfields or regional airfield/ airspace systems	Runway, taxiways, aprons, gates, and/or airspace; complex airfields (e.g., runway crossings and airspace fix constraints), flexible input	Greatest level of detail about aircraft flight schedule and airfield and airspace configurations, including taxiing routes and aircraft parking positions

Source: LeighFisher.

- **Modeling assumptions:** Fixed, built-in assumptions within the level of modeling sophistication that cannot be altered through input parameters (i.e., what assumptions are hardwired into the model and cannot be changed?)
- **Data requirements:** Required data inputs for the level of sophistication (i.e., what are the data requirements for defining the inputs and validating the outputs of the modeling?)
- **Time and cost requirements:** Typical time and cost required for a capacity analysis using that level of modeling sophistication (i.e., what are the approximate resource requirements in terms of both elapsed time and cost?)
- **Model availability:** Cost and process for acquiring the model (i.e., is the model publicly available, and what is the cost associated with acquiring the model?)
- **Operator skill and training required:** The specific background, knowledge, and training required for the user to effectively use the tools under each level of sophistication

Level 1—Table Lookup

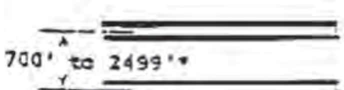
This level of modeling sophistication refers to capacity analyses completed by table reference, as exemplified in Chapter 2 of the AC and the prototype Airfield Capacity Spreadsheet Model described in Chapter 4 of this guidebook. The table reference mainly involves looking up an airport's runway configuration along with certain other airport characteristics, most commonly fleet mix, to determine hourly runway capacity and annual service volume (ASV) in visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) (Figure 3-1).

Applications

Table lookup methods typically consider runways only and are best used for high-level capacity analyses conducted as part of the creation of airport system plans or smaller airport master plans. The most suitable applications of this level of modeling sophistication are estimations of (1) existing hourly runway capacity and ASV, or (2) major capacity changes, such as those associated with additional runways, new runway configurations, increased spacing between runways, or a significant change in aircraft fleet mix.

Modeling Assumptions

This level of modeling sophistication cannot capture or change any of the default assumptions used in estimating the hourly capacity and ASV values presented in the tables. The AC provides capacity estimates for 19 runway configurations, representative of typical U.S. airports that have these configurations. However, if an airport's runway configuration is not included, or if operational conditions differ from those assumed for the tables, this method cannot be used. For example, standard IMC/VMC separations are assumed in the capacity values, and these assumptions cannot be adjusted. In the AC, it has been assumed that the airport has no airspace limitations and that, if instrument flight rules (IFR) capacity is desired, at least one runway is equipped with an instrument landing system (ILS). In addition, these assumptions cannot be altered to reflect future technologies or changes in flight procedures. Also, it has been assumed in the AC that each runway has a full-length parallel taxiway. Tables that can be used to estimate

Runway-use Configuration	Mix Index %(C+3D)	Hourly Capacity Ops/Hr VFR	Hourly Capacity Ops/Hr IFR	Annual Service Volume Ops/Yr
	0 to 20	98	59	230,000
	21 to 50	74	57	195,000
	51 to 80	63	56	205,000
	81 to 120	55	53	210,000
	121 to 130	51	50	240,000
	0 to 20	197	59	355,000
	21 to 50	145	57	275,000
	51 to 80	121	56	260,000
	81 to 120	105	59	285,000
	121 to 180	94	60	340,000

Source: Federal Aviation Administration.

Figure 3-1. Portion of lookup table from the AC.

the effects of a partial parallel taxiway or no parallel taxiway are not provided in this section of the AC, although a figure is provided in Chapter 4 (Figure 4-26) for this purpose.

Data Requirements

The data requirements for table lookups are minimal, requiring only airport runway configuration and percentage of large and heavy aircraft in the fleet mix. Aircraft fleet mix data typically are readily available from airport records, OAG (formerly Official Airline Guide), or from FAA's Enhanced Traffic Management System Counts (ETMSC). It is reasonable to assume that at smaller airports very few large and no heavy jet aircraft are in the fleet mix. Little or no opportunity or capability exists to improve the quality of the Level 1 capacity estimates with additional or improved data and assumptions.

Time and Cost Requirements

This method of capacity analysis requires a small investment commensurate with the fidelity of the capacity estimate obtained through these methods. Completing a capacity analysis with this level of sophistication can be expected to take about a day, and would likely cost less than $5,000.

Model Availability

Level 1 models are publicly available as part of the AC, which is available free of charge on the FAA website (www.faa.gov).

Other Factors

Chapter 2 of the AC was last updated in 1983. Despite the age of the method contained in the AC, it is still widely used in the United States and worldwide. However, the method does not allow for consideration of (1) changes that have occurred in ATC rules and procedures since 1983, or (2) variations in assumed ATC rules or future flight procedures and their effects on the capacity of different runway configurations. The data presented in the table lookup method could be updated to reflect current rules and procedures, but the methodology still could not be used to evaluate future rules and procedures, such as those that might be associated with NextGen technologies.

Level of Operator Skill and Training Required

Users of the table lookup method need to have a basic knowledge of airfield operations and the factors that affect airfield capacity, such as aircraft fleet mix, runway use configuration, and weather conditions. With such a background, little or no training is required for using the table lookup method.

Summary of Limitations

The main limitations of the currently available techniques at this level of sophistication are the unchangeable built-in assumptions for calculating the capacities and the limited number of runway use configurations available (currently 19 in the AC). The values of hourly and annual capacity provided in Chapter 2 of the AC are derived from typical capacities achieved at U.S. airports that have similar runway use configurations, reflecting ATC rules and procedures from 1983. However, when more precise capacities are required, or if the conditions at the airport do not match the built-in assumptions, a higher level of modeling sophistication must be used.

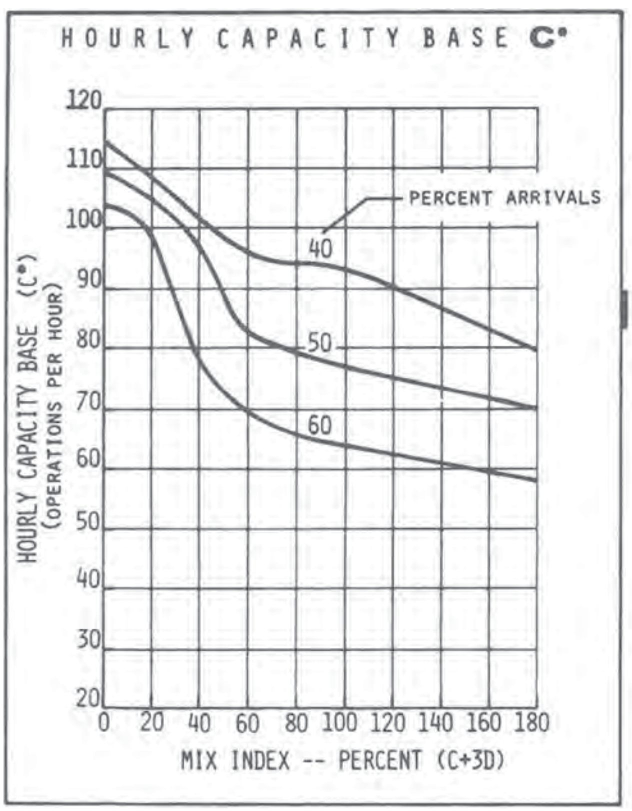
Nevertheless, the existing table lookup method is adequate for the purposes of calculating a quick, broad-brush, runway-focused capacity estimate for an airport with an airfield configuration available in the lookup table and with operating characteristics that follow the underlying assumptions. Otherwise, a higher level of modeling sophistication should be used.

Level 2—Charts, Nomographs, and Spreadsheets

This level of modeling sophistication refers to capacity analyses completed for a wide range of runway use configurations and operating alternatives through the use of charts and nomographs, as presented in Chapter 3 of the AC. Level 2 modeling gives the user some additional flexibility in specifying operating conditions at the airport.

To calculate hourly runway capacity, this method requires the selection of the best representation of ceiling, visibility, and runway use configurations from a diagram of various runway use configurations. The user must then find the corresponding charts or nomographs for the selected case.

Figure 3-2 illustrates the charts/nomographs method as applied to a particular runway use and weather condition. As shown in the figure, the capacity represented by the selected configuration is determined from the graph, relating mix index with hourly airfield capacity for different



TOUCH & GO FACTOR T

Percent Touch & Go	Mix Index--Percent (C+3D)	TOUCH & GO FACTOR T
0	0 to 180	1.00
1 to 10	0 to 70	1.03
11 to 20	0 to 70	1.06
21 to 30	0 to 40	1.13
31 to 40	0 to 10	1.26
41 to 50	0 to 10	1.33

C* x T x E = Hourly Capacity

EXIT FACTOR E

To determine Exit Factor E:

1. Determine exit range for appropriate mix index from table below
2. For arrival runways, determine the average number of exits(N) which are: (a) within appropriate exit range, and (b) separated by at least 750 feet
3. If N is 4 or more, Exit Factor = 1.00
4. If N is less than 4, determine Exit Factor from table below for appropriate mix index and percent arrivals

Mix Index--Percent (C+3D)	Exit Range (Feet from threshold)	EXIT FACTOR E								
		40% Arrivals			50% Arrivals			60% Arrivals		
		N=0	N=1	N=2 or 3	N=0	N=1	N=2 or 3	N=0	N=1	N=2 or 3
0 to 20	2000 to 4000	0.86	0.88	0.94	0.80	0.85	0.93	0.71	0.83	0.93
21 to 50	3000 to 5500	0.84	0.91	0.98	0.71	0.85	0.92	0.71	0.85	0.92
51 to 80	3500 to 6500	0.81	0.91	0.97	0.76	0.85	0.91	0.75	0.84	0.91
81 to 120	5000 to 7000	0.83	0.90	0.95	0.80	0.86	0.92	0.90	0.87	0.92
121 to 180	5500 to 7500	0.93	0.99	1.00	0.84	0.94	0.98	0.85	0.94	0.98

Source: Federal Aviation Administration.

Figure 3-2. Portion of chart/nomograph from the AC.

percentages of arrivals. The capacity can then be further adjusted to account for (1) the percentage of touch-and-goes (training flights) at the airport and (2) runway exit factors, through the application of various adjustment factors determined from the charts and information about the traffic at the airport and the number of runway exits and their locations. This method can be repeated for all runway use configurations and weather conditions at the airport.

If desired, ASV can then be calculated by first taking the weighted average of the hourly capacities over the year (which is computed using formulas specified in the AC), and then expanding that weighted average up to an annual number by multiplying by the ratio of average day, peak month (ADPM) operations to peak-hour operations, and the ratio of annual operations to ADPM operations. Thus, ASV is calculated using the following formula:

$$ASV = C_w \times D \times H,$$

where

C_w = the weighted average hourly capacity of the airfield,
D = the ratio of annual to ADPM demand, and
H = the ratio of ADPM demand to peak-hour demand.

The D and H can be determined from airport records or publicly available sources on air traffic demand patterns. In cases where such demand data are not available, the recommended default values in the AC can be used.

Applications

This method for calculating airfield capacity is more refined than the table lookup method. However, Level 2 modeling is still considered best used for high-level capacity analyses conducted as part of the development of system plans or master plans because the charts and nomographs generalize the airport's operating configuration and activity. The chart and nomograph method is generally considered most suitable for smaller airports and simpler runway configurations, and preliminary evaluations where limited resources are available. The most suitable applications of this level of modeling sophistication are estimations of (1) individual capacity-related components, (2) hourly airfield capacity and ASV, or (3) major capacity changes, such as those associated with additional runways, new runway configurations, or increased spacing between runways.

Modeling Assumptions

This level of modeling sophistication cannot capture or reflect operational constraints or deviations from the assumptions used in developing the charts and nomographs included in the AC. The AC provides capacity estimates for 43 runway configuration and weather combinations, representative of typical U.S. airports. However, if an airport's runway configuration is not included, or if specific operating constraints are not included, then this method cannot be used. Standard IFR/VFR separations are assumed in the capacity values, and these assumptions cannot be adjusted. It was assumed in the AC that the airport would have no airspace limitations and that the AC would not apply to situations such as the absence of an Airport Traffic Control Tower (ATCT), a parallel taxiway, or an ILS, except as provided in the previously mentioned Figure 4-26 of the AC. This section of the AC also would not apply to airports that have aircraft type restrictions on certain runways. In addition, there is no possibility of altering these assumptions to reflect future technologies or changes in flight procedures. The new Prototype Airfield Capacity Spreadsheet Model developed in the research for ACRP Project 03-17 and described in Chapter 4 of this guidebook has been designed to overcome many of these limitations.

Data Requirements

The data requirements for this method are minor, requiring airport runway configuration and airport geometry/layout information, specified percentages of large and heavy aircraft in the fleet mix, and exit locations and percentage of arrivals. Nearly all of this information is readily available from airport records, the OAG, or FAA's ETMSC. At smaller airports, it is reasonable to assume that relatively few large and no heavy jet aircraft are in the aircraft fleet mix. Limited opportunity and ability exist to improve the quality of the Level 2 capacity estimates using additional or improved data and assumptions. However, the quality of the estimates does depend on the quality of the data on aircraft fleet mix, runway exit locations, and percentage of arrivals in the peak demand period.

Time and Cost Requirements

This method of capacity analysis requires only a small investment, commensurate with the fidelity of the capacity estimate obtained through this method. Completing a capacity analysis with this level of sophistication can be expected to take a few days to a week, and would likely cost less than $25,000.

Model Availability

Level 2 methods are publicly available as part of the AC, which is available for download from FAA's website free of charge. A copy of the Prototype Airfield Capacity Spreadsheet Model developed in this research and described in Chapter 4 of this guidebook is available on the CD-ROM provided with the guidebook.

Level of Operator Skill and Training Required

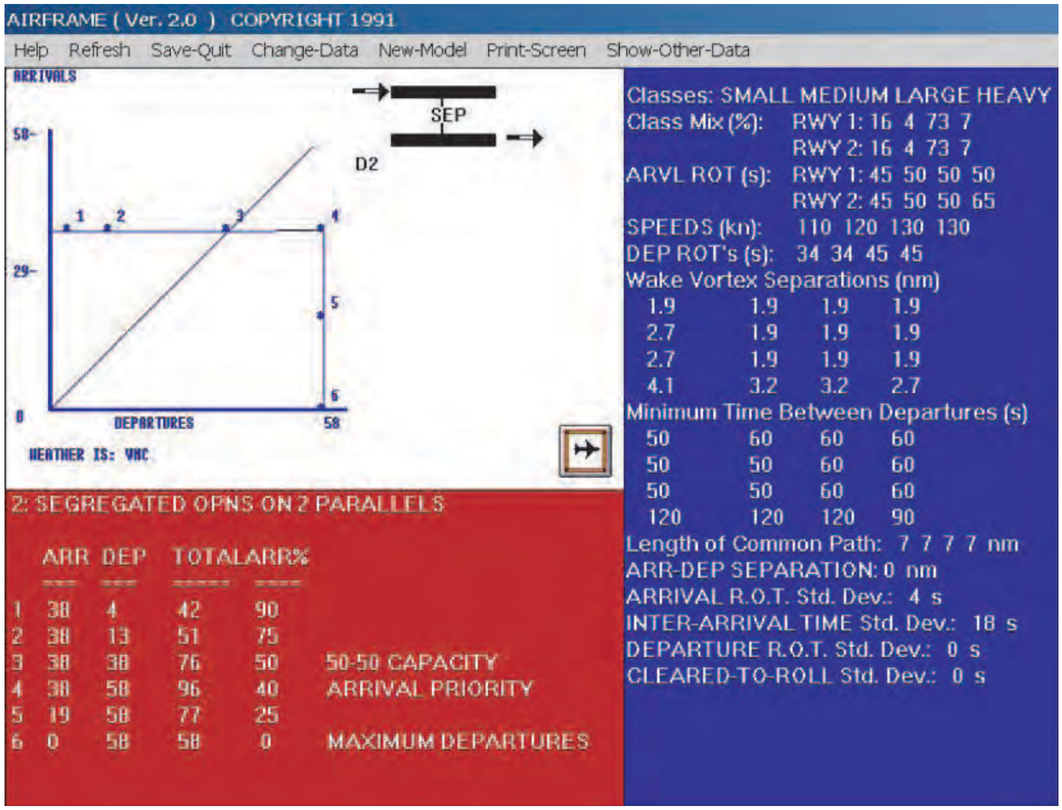
As with Level 1 models, users of these Level 2 charts/nomographs need to have a basic knowledge of airfield operations and the factors that affect airfield capacity, such as aircraft fleet mix, runway use configuration, and weather conditions. In addition to the Level 1 requirements, Level 2 users need to have an understanding of the specified percentages of arrivals, training flights (touch-and-goes), and the effects of the number and locations of exit taxiways on arrival runway occupancy times. With such a background, little or no training would be required to use the Level 2 charts and nomographs method.

Summary of Limitations

The main limitations of the currently available techniques at this level of sophistication are the limited flexibility inherent in the charts and nomographs and the unchangeable built-in assumptions associated with the 43 runway use configurations available. The values of hourly and annual capacity available in Chapter 3 of the AC may still reasonably apply to U.S. airports that have similar runway use configurations, but there is room for improvement and refinement at this level. Although this methodology presents greater flexibility than the table lookup method, in situations where more precise capacities are required—or if the conditions at the airport do not match the built-in default assumptions of the charts and nomographs—a higher level of modeling sophistication must be used.

Level 3—Analytical Capacity Models

This level of modeling sophistication refers to capacity (i.e., maximum throughput) analyses generated through analytical computer models, such as FAA's ACM and the LMI Runway Capacity Model. Figure 3-3 shows a typical ACM graphical user interface.



Source: Graphical User Interface (GUI) developed by Barrer Aviation Software.

Figure 3-3. ACM graphical user interface.

A typical analytical airfield capacity model can accept input assumptions and information on the following factors affecting airfield capacity:

- Runway configuration
- Types of operations (arrivals, departures, or both) assigned to each runway
- Aircraft mix on each runway
- Aircraft performance characteristics (e.g., minimum separation requirements, final approach speed, and runway occupancy times for arrivals and departures)
- ATC rules and procedures (e.g., actual or standard separations, simultaneous runway occupancy), length of final approach, and flight rules based on ceiling and visibility (e.g., dependencies between runways and number of simultaneous movements)
- Runway occupancy times and actual achievable average separation values, modeled as random variables (i.e., the user can specify a mean and standard deviation for these parameters from which buffers are estimated)

The output of this model is an estimate of the hourly capacity of the runway system for any specified arrival-departure ratio or percentage of arrivals. A capacity arrival-departure envelope, which is often referred to as a Pareto frontier, also can be generated.

Applications

These models are applied in specialized airfield capacity studies, airport master plans, and regional airport system plans. This approach is limited to analysis of (1) the capacity of runways only (although taxiways and airspace constraints can be reflected implicitly), (2) systems of runway configurations with moderate complexity and straightforward arrival and departure runway use procedures.

Modeling Assumptions

To use this model, the runway configuration must be available in the model, or be able to be represented by externally combining available configurations. Any limitations on aircraft types that can use a certain runway (e.g., because of length or noise restrictions) must be reflected externally to the model. A major assumption of this class of models is that taxiways and gates have little effect on determining airfield capacity. "Continuous demand for service" assumptions are associated with the configuration and operation of the departure and arrival airspace.

Data Requirements

The data requirements for analytical capacity models are more demanding than for the Level 1 or 2 models, yet not as complicated as those for a simulation-based model. Most data needed for Level 3 models can be compiled from readily available sources. Inputs include fleet mix, arrival and departure runway occupancy times, arrival-arrival separations, departure-departure separations, and arrival-departure separations (i.e., how far out from the threshold an arrival must be to release a departure on the same or a dependent runway). Default values can be used for most of these inputs, excluding fleet mix, although the results would not be as precise as using data based on actual runway occupancy or separation through analysis of airborne and surface radar track data. In Level 3 modeling, a minimum amount of data will yield *an* answer, but this answer can become more refined or precise with the addition of more (and more airport-specific) data.

Time and Cost Requirements

This method of capacity analysis requires a moderate investment. Inputs to the models, such as the distribution for runway occupancy times and the standard minimum or actual aircraft separations, can be obtained from standard sources or can be developed through the processing and analysis of airborne flight path data (radar flight tracks) and surface track data (e.g., radar ASDE-X). Completing a capacity analysis using these analytical models can be expected to take a few weeks and would likely cost up to about $50,000.

Model Availability

The primary Level 3 model, ACM, is available free of charge from FAA. The other models in this category—the LMI Runway Capacity Model and FTA's RUNCAP model—are proprietary.

Level of Operator Skill and Training Required

As with Level 1 and Level 2 models, users of Level 3 analytical capacity models need to have a basic knowledge of airfield operations and the factors that affect airfield capacity, such as aircraft fleet mix, runway use configuration, and weather conditions, as well as an understanding of the percentage of arrivals, training flights, and the effects of the number and locations of exit taxiways on arrival runway occupancy times. In addition to the Level 1 and 2 requirements, Level 3 users need to have an understanding of ATC rules and procedures and aircraft performance. Unlike Levels 1 and 2, a substantial amount of training is required to properly use the Level 3 analytical capacity models, including preparing model inputs, interpreting and analyzing model outputs, and representing airport-specific conditions implicitly. In addition, the Level 3 user must be more computer literate, because, at least in the case of the ACM, the model is not very user-friendly.

Summary of Limitations

This approach is limited to capacity analysis of the runways only (although taxiways and airspace constraints can be reflected implicitly), and is limited to analysis of systems of runway configurations with moderate complexity. FAA's ACM also has the following limitations (which may or may not apply to other models in this category):

- Some of the basic assumptions regarding arrival-departure separation requirements are hard-wired into the ACM legacy code. Any deviations from those assumptions require changes to and recompiling of that code.
- Inability to directly account for taxiway and airspace constraints. These effects must be accounted for externally to the model and may require additional training.
- Lack of flexibility in modeling runway configurations explicitly. Complex airfields must be analyzed by piecing together capacity estimates for components of the overall airfield operation, and such post-analysis may require additional training.
- Lack of flexibility in representing airfields that have runways with aircraft fleet mix restrictions. A substantial amount of post-analysis is required to reflect such aircraft fleet mix restrictions, which may require additional training.

Level 4—Airfield Capacity Simulation Models

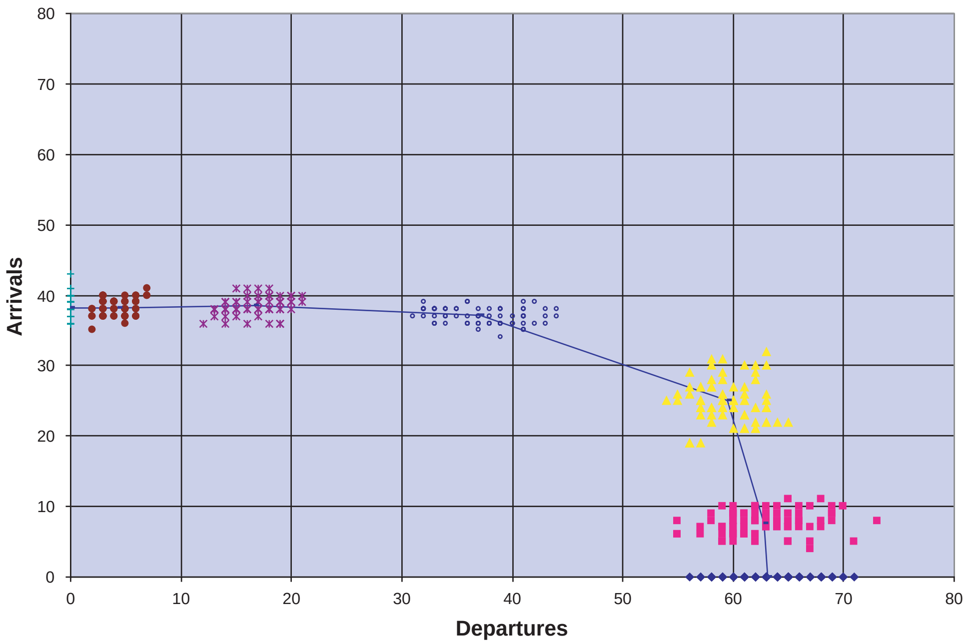
This level of modeling sophistication refers to a level between the Level 3 analytical models, as represented by the ACM, and the Level 5 aircraft delay simulation models, as represented by SIMMOD, TAAM, and other models. This level of modeling sophistication allows the user to analyze complex runway use configurations with airport-specific ATC procedures and potential physical and environmental constraints. Two models that fit into this level are: (1) the MITRE *runway*Simulator, and (2) the FTA Flexible Airport Simulation (FLAPS) model.

Applications

This level of modeling is best used to estimate an hourly throughput capacity of a runway system for a complex airfield, or for airport-specific operating procedures. New technologies and flight procedures can be represented in both models through use of the input parameters for aircraft operations, statistical buffers, runway dependencies, aircraft flight paths and profiles, and assumptions regarding required spacing between parallel runways. Both the *runway*Simulator and FLAPS can include the effects of runway exit/entrance taxiways on airfield capacity. However, other taxiways on the airfield, such as parallel taxiways, connector taxiways, or runway-crossing taxiways, are not explicitly included in the Level 4 models.

Modeling Assumptions

To calculate a throughput capacity, Level 4 models do not use a detailed flight schedule. Instead, a saturated-conditions schedule is assumed, represented by a continuous arrival and departure stream in proportion to the fleet mix (which the user inputs). The arrival and departure stream is characterized by there always being aircraft waiting to land and take off (i.e., a continuous demand for service with no slack periods). The primary output of interest of the Level 4 models is runway throughput, not aircraft delay, although it appears that



Source: MITRE Corporation.

Figure 3-4. Capacity curve or Pareto Frontier generated by the MITRE runway**Simulator** ***showing clusters of points for each arrival-departure ratio.***

the models can provide both. A typical output chart from the *runway*Simulator is shown in Figure 3-4. Each plotted point represents the capacity estimate for 1 hour of the simulation at a certain arrival percentage. The clusters of plotted points are averaged to a centroid representing a particular percentage of arrivals, and these centroids are connected to draw a Pareto frontier or capacity curve.

Until recently, *runway*Simulator 2010 had two modes for modeling arrival runway occupancy times (AROTs). The first mode used an underlying trajectory landing-roll model, which incorporated aircraft performance parameters for touchdown speed, deceleration, and exit speed. The second mode involved drawing an AROT from a user-specified distribution and recomputing the deceleration parameter that would realize it. Both modes had arrivals exiting at modeled exit locations. The version of *runway*Simulator tested in ACRP Project 03-17 used a single mode, for which only the drawn AROT applied and the exit locations were ignored. The newest version of *runway*Simulator, expected to be released in 2012, will support the two modes again, with the following adjustments: (1) use of the underlying trajectory landing-roll model will use exits, and (2) drawn AROTs will not.

Data Requirements

The Level 4 models require more detailed input data and assumptions than the Level 3 models, but less than the Level 5 models. The FLAPS model requires more detailed input data than does *runway*Simulator because FLAPS explicitly models the aircraft landing, rolling out, and runway exiting process. The input stream contains essentially the same data as the Level 3 models, but at a greater level of detail. For example, close-in arrival and departure flight track geometries can be specified, and the user can specify aircraft fleet mix by runway. In Level 4 modeling, an answer can be obtained using a minimum amount of data, but the answer can become more refined or precise with the introduction of additional data.

Time and Cost Requirements

The investment required to apply a Level 4 model is somewhere between the investment required for the Level 3 analytical models and the investment required for the Level 5 aircraft delay simulation models, depending on the complexity of the problem. Because of their computational efficiency and simple input structures, the *runway*Simulator and FLAPS models are characterized by a very low cost per computer run compared with Level 5 models. Typically, a Level 4 model takes several weeks to a month to set up and run, and an application of a Level 4 model would likely cost between $50,000 and $100,000, depending on the level of complexity of the issues being analyzed.

Model Availability

Currently, no model in this category is publicly available, as both *runway*Simulator and FLAPS are proprietary. According to the MITRE Corporation, *runway*Simulator will be made available to the public for a nominal licensing charge sometime in 2012.

Level of Operator Skill and Training Required

As with Levels 1, 2, and 3, Level 4 airfield capacity simulation models require operators to be familiar with airfield operations and the factors that affect airfield capacity, such as aircraft fleet mix, runway use configuration, and weather conditions. Operators must also have an understanding of the percentage of arrivals, training flights, the effects of the number and locations of exit taxiways on arrival runway occupancy times, and an even more detailed understanding of ATC rules and procedures and aircraft performance in landing and takeoff. Compared with the Level 3 models, proper use of the Level 4 models requires extensive training that includes preparing model inputs, interpreting and analyzing model outputs, calibrating the model, and representing complex runway operations and dependencies between movements.

Taxiway Configurations

Both the *runway*Simulator and the FLAPS model consider only the runways and exit/entrance taxiways, not the other taxiways on the airfield, such as parallel taxiways, connector taxiways, or runway-crossing taxiways. However, parallel taxiways can be modeled implicitly through the input parameters for runway occupancy times, and crossing taxiways can be modeled implicitly through other input assumptions.

Variability

The *runway*Simulator has six sources of randomness: flight generation, arrival runway occupancy times, departure runway occupancy times, arrival release times, departure release times, and times between departure release and start of roll. The developers of the *runway*Simulator experimented with random buffer sizes at one point but abandoned that approach. Instead, statistical variability of aircraft separations is represented implicitly in *runway*Simulator by applying the assumed statistical excess-spacing buffers to the minimum separation requirements.

FLAPS is a stochastic, event-driven simulation model that produces statistical outputs on runway capacity and use, aircraft delays, exit use, and runway queues.

Other Factors

The *runway*Simulator software runs on a personal computer (PC) running Microsoft Windows® and currently requires runtime licenses from Wolverine Software for the SLX and Proof

Animation (Proof) software used by the current simulation engine (i.e., *runway*Simulator 2010). However, MITRE expects to eliminate the requirement for a separate SLX license in the version of the *runway*Simulator that is expected to be made public in 2012.

Summary of Limitations

The main limitations of the Level 4 models are that they consider runways only and exit/entrance taxiways, not the entire taxiway system, except that both models can reflect, at least implicitly, (1) runway exit taxiways and parallel taxiways through the definition of runway occupancy times, and (2) entrance taxiways through potentially longer-than-typical departure-departure separations. Level 4 models also require a more sophisticated user with a greater understanding of complex airfield operations and simulation models.

Level 5—Aircraft Delay Simulation Models

Aircraft delay simulation models represent the highest level of modeling sophistication for evaluating runway capacity and measuring aircraft delay within a single modeling environment. Historically, simulation models were developed to analyze complex airport and airspace operating environments where multiple factors, such as airfield configuration, terminal aprons, airspace limitations, and aircraft activity, interact in ways that simpler models cannot represent.

Multiple examples of simulation models have a long history of use over the past 30 years. Most recently, TAAM and SIMMOD have been the most widely used models (see Figure 3-5). However, RDSIM, ADSIM, and the AirTOp Fast Time Simulator by AirTOpsoft are also in current use.

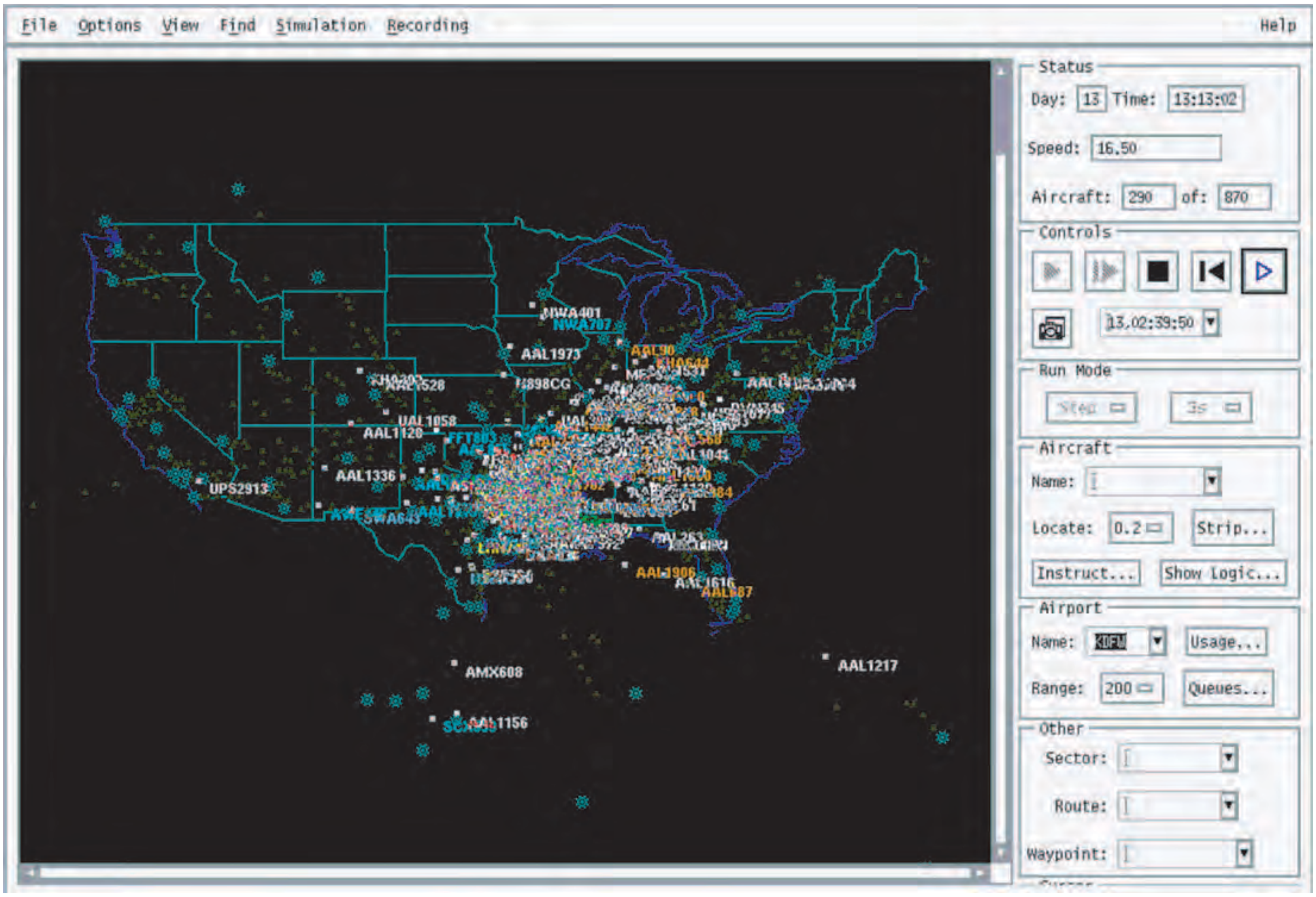
The following characteristics differentiate simulation models from less sophisticated models:

- They represent aircraft activity as a flight schedule showing aircraft travel through the airport (e.g., landing, gate-in, gate occupancy, gate-out, and takeoff).
- They have the ability to model apron-gate operations and aircraft taxiway movements.
- They use networks to represent the airport's surface configurations (i.e., runways, taxiways, and gates) and networks or flight routes to represent airspace configurations (i.e., approach and departure routes).

The ability of Level 5 simulations to model detailed aircraft movements along taxiways and through the airspace makes them more difficult and time-consuming to set up, run, and calibrate than the lower-level models. Some Level 5 models provide user flexibility to scale down the level of fidelity for a particular application (e.g., users can operate with runways only or with gate areas instead of individual gates).

Applications

Level 5 models are best used to analyze complex capacity issues involving aspects of airfield operations not focused on the runways (i.e., aprons, taxiways, and airspace), or to analyze interactions between multiple aspects of the airfield. Simulation models provide a high degree of fidelity for capacity issues that may be subject to intense public scrutiny. Level 5 models also are needed if estimates of metrics such as aircraft taxi time and delay are required. In situations where visual validation and computer animation graphics are needed, the use of Level 5 models would also be required. Finally, Level 5 models are required for the analysis of detailed flight schedules.



Source: LeighFisher.

Figure 3-5. Screen shot generated by TAAM showing traffic to and from Dallas/Fort Worth International Airport.

Modeling Assumptions

Very few built-in assumptions are associated with Level 5 models; most inputs are variables, so that users can define their specific airfield and airspace situation through the model inputs.

Data Requirements

Simulation models require a high level of detail about aircraft operations and airfield and airspace configurations, which requires an extensive data gathering and analysis effort. As with lower levels of modeling, in Level 5 modeling a minimum amount of data will yield an answer, but this answer can become more refined or precise with the introduction of additional data. Even more than at previous levels of modeling, however, the outputs of a Level 5 model will only be as good as the input data and assumptions provided by the user.

Time and Cost Requirements

Simulation models take significant resources to set up and calibrate. Data collection and model calibration take a significant amount of time. Detailed discussions with air traffic and airport operations specialists and airport users are often required to properly represent the baseline operating conditions and proposed changes. However, once a simulation model has been set up and calibrated, it can be run for additional cases fairly quickly. Thus, the most cost-effective use of simulation modeling is when multiple problems are anticipated to be evaluated so that the calibrated model can be used more than once. Level 5 simulation models may take several months to be properly set up and calibrated to provide representative capacity and delay estimates, and they would likely cost more than $100,000 to apply to a complex airport and set of experiments.

Model Availability

Most simulation models are not available free of charge to the public. One exception is the base version of FAA's SIMMOD, which is available from FAA free of charge; other versions of SIMMOD must be purchased or leased from the model vendor, ATAC Corporation. Similarly, TAAM licenses must be obtained from Jeppesen/Boeing on a monthly basis.

Level of Operator Skill and Training Required

As with Level 4 models, users of Level 5 aircraft delay simulation models need to be very familiar with airfield operations, factors that affect airfield capacity, the effects of traffic and runway configurations on occupancy times, ATC rules and procedures, and aircraft performance in landing and takeoff. In addition to the Level 4 requirements, Level 5 users need to have a detailed understanding of aircraft performance on the taxiway system and in the apron-gate area, and detailed knowledge of airline flight schedules. Compared with the Level 4 models, the proper application of Level 5 models requires even more extensive training, including preparing model inputs, interpreting and analyzing model outputs, and representing complex runway, taxiway, and apron-gate operations, in a greater level of detail than for Level 4.

Taxiway Configurations

Level 5 aircraft delay simulation models are the only tools available to model taxiway and other airfield operations that do not directly support runway operations, which could include parallel taxiways, circulation taxiways, bypass taxiways, crossover taxiways, apron-edge taxiways, apron taxilanes, and holding bays.

Variability

Most simulation models incorporate a number of random variables to account for the natural variability in flight schedules, aircraft performance, and airport operations. Most simulation models do not incorporate random variability in aircraft taxiing speeds and tend to model all aircraft taxiing operations at the same speed, although different taxiway-speed groups can typically be defined for different taxiway categories or locations. Some Level 5 simulation models simplify aircraft landing roll performance modeling, limiting the ability to model this key airfield capacity determinant.

Other Factors

Complex aircraft delay simulation models should be calibrated against actual data on aircraft taxiing times, aircraft flow rates, and aircraft delays. These comparative data generally can be obtained from FAA's Aviation System Performance Metrics (ASPM) database; however, the user must be careful to obtain the aircraft delay data that are most comparable to aircraft delay estimates produced by the aircraft delay simulation models, which basically can be defined as excess travel times or the times that aircraft spend waiting to land, waiting for a gate, waiting to push back, waiting to depart, and so forth. Calibration is critical to ensure that the logic in the model, most often related to runway loadings and aircraft separation, is not more efficient or precise than what human controllers and pilots could realistically achieve.

Summary of Limitations

The main limitations of simulation models are the time and cost required to set up and calibrate the models and the requirement for a well-trained and knowledgeable user. These models also involve a large number of variables, and there is a considerable learning curve to use the models and check the results.

CHAPTER 4

New Airfield Capacity Evaluation Tools and Guidance

One of the main objectives of this ACRP research project was to identify gaps in existing models and recommend new or enhanced models to fill those gaps. Based on the review of the existing models discussed in Chapter 3, two major gaps were identified:

1. Level 1 and Level 2 methods that provide the flexibility for the user to input assumptions that differ from those used to create the existing Level 1 and 2 tables and charts/nomographs in order to better represent the user's specific conditions
2. A Level 4 capacity simulation model for estimating the maximum sustainable throughput of complex airfield layouts that is specifically designed for that purpose and available to the public

This chapter addresses the limitations of existing modeling techniques by introducing and reviewing new and newly available modeling tools. In addition, this chapter provides guidance for taking into account factors that influence airfield capacity but typically are not directly considered in existing airfield capacity models.

Overview of New and Newly Available Models

The new and newly available modeling tools shown in Figure 4-1 are described in this section in terms of how they differ from existing models, their recommended applications, their limitations, and recommended further development.

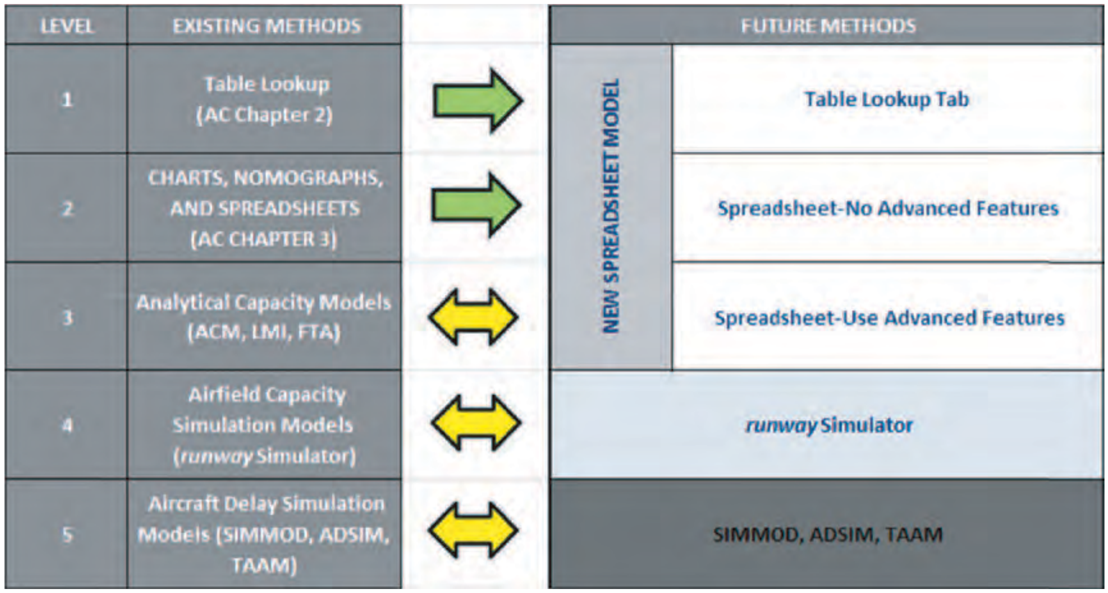
The new spreadsheet-based model encompasses the capabilities of the existing capacity estimation techniques at Levels 1 and 2, but has much greater flexibility for inputting case-specific assumptions to represent the user's unique conditions. Moreover, the Level 3 spreadsheet is much more user-friendly and transparent than the existing FAA Airfield Capacity Model (ACM); however, it will require further development to encompass all runway use configurations currently included in the ACM.

The newly available Level 4 model, the *runway*Simulator, which the MITRE Corporation plans to make publicly available in 2012, has been reviewed and validated. This model is expected to become the "model of choice" for evaluating the capacity of complex airfields.

The Level 5 models are outside the scope of this guidebook but it is expected that they will continue to be used as they are today.

New Prototype Airfield Capacity Spreadsheet Model (Levels 1, 2, and 3)

A new prototype set of Excel spreadsheets was developed as part of this research project. This prototype modeling tool is intended to help airport planners understand and determine airfield capacity at a higher fidelity than AC 150/5060-5, *Airport Capacity and Delay* (the AC), but with



Source: ACRP Research Team.

Figure 4-1. Overview of relationship between existing and new models.

much less effort than required to apply aircraft delay simulation models like the Simulation Model (SIMMOD) and Total Airspace and Airport Modeler (TAAM). The new spreadsheet model, here referred to as the Airfield Capacity Spreadsheet Model, should be considered a prototype.

Capabilities/Description

For many years, the ability to quickly estimate airfield operational capacity has been limited to rules of thumb for simple configurations and a lookup table provided in the AC. The Airfield Capacity Spreadsheet Model was developed as an intermediary between the lookup tables available in the AC (some of which are replicated using new calculations in the spreadsheet model) and the Level 4 and 5 simulations.

The Airfield Capacity Spreadsheet Model is built on base calculations following the methodology in the ACM program and applies variable separation, spacing, and clearance standards following the guidelines included in FAA JO 7110.65, *Air Traffic Control,* and FAA EM-78-8A, *Parameters of Future ATC Systems Relating to Airport Capacity/Delay.* FAA's ACM is discussed in detail in FAA RD-76-128, Reference 1, *Model User's Manual for Airfield Capacity and Delay Models.* These references are further described in Appendix B.

The Airfield Capacity Spreadsheet Model is designed to be a working planning tool, similar to the ACM but with more flexibility to change input assumptions to represent site-specific conditions from the most simple airfield configurations to moderate airfield configurations.

Improvements and Differences from Previous Models

The Airfield Capacity Spreadsheet Model is intended to serve as a beginning-level capacity calculation option. For cases where a detailed analysis is not warranted, either because of budgetary or airport conditions, this new model can provide timely and accurate airfield capacity estimates for simple to moderately complex airfields. The model is not intended to be used for complex airfield configurations or when a higher degree of specificity is required (e.g., to support large-scale airfield redevelopment projects or highly controversial capacity projects).

The Airfield Capacity Spreadsheet Model can be used when limited data are available. Many of the base default parameters that can be used for simple single or dual runway airfields without significant unique restrictions are contained in the spreadsheet model. Checklists provided in this guidebook can help determine the level of data available for the modeling task anticipated and the level of modeling sophistication that can be achieved with the available data. The new spreadsheet model also includes a simplified tab similar to the table lookups in the AC but focusing only on the airfield configurations currently in the Airfield Capacity Spreadsheet Model.

The spreadsheet model user is assumed to have limited knowledge of air traffic control (ATC) or FAA rules and guidelines on air traffic and pilot procedures regarding approaches and departures. The explanations provided in the Capacity Spreadsheet Model User's Manual in Appendix A of this guidebook are intended to provide sufficient understanding for planners to successfully use the new model, although they do not provide sufficient detail to serve as a tutorial on airfield capacity planning.

Recommended Uses/Applications

The Airfield Capacity Spreadsheet Model is most applicable to small to midsized airports, airports without complex airfield layouts, and airports for which a detailed capacity analysis is unnecessary. At present, the Airfield Capacity Spreadsheet Model can be used to calculate average hourly capacity levels only for the following general airfield configurations:

- Single runway
- Dual parallel runways
- Dual intersecting runways

Each general configuration can be uniquely adjusted to closely fit the conditions of the user's specific airfield through selected input parameters. The following parameters can be modified in the Airfield Capacity Spreadsheet Model to estimate the effect on resulting airfield capacity:

- Aircraft fleet mix
- Visual meteorological conditions (VMC) versus Instrument meteorological conditions (IMC)
- Arrival runway occupancy time
- Average aircraft approach speeds
- Runway exit availability
- Type of parallel taxiway (full, partial, or none)
- Availability of an air traffic control tower (ATCT)
- Runway crossings
- Percent of touch-and-go activity
- Length of common approach
- Departure-arrival separation
- Arrival gap spacing buffer
- Departure hold buffer
- Arrival-arrival separation requirements
- Departure-departure separation requirements

Changes can be made to the defaults in the model to test the results of the various parameters listed above.

Airfield Capacity Spreadsheet Model—Sample Results for Levels 1, 2, and 3

Outputs from the Airfield Capacity Spreadsheet Model can be used as Level 1, Level 2, or Level 3 modeling results.

For Level 1, the model file includes an example of a new lookup table that presents five airfield configurations comparable to those in the AC.

Figure 4-2 presents a screen shot of a lookup table generated using the Airfield Capacity Spreadsheet Model. This example incorporates capacity estimates developed with the listed assumptions in Chapters 1 and 2 of the AC and follows the general guidelines in the User's Guide in Appendix A of this guidebook.

In the Level 1 method, the user only makes an assumption regarding the fleet mix that most closely represents the actual aircraft fleet mix at the airport in question, and reads the hourly capacity and annual service volume (ASV) estimates for the comparable airfield configuration. If desired, the user can use the Airfield Capacity Spreadsheet Model Level 2 and 3 methods to assess the capacity of a more specific fleet mix.

The lines between Level 2 and Level 3 modeling become blurred when considering the Airfield Capacity Spreadsheet Model, because the spreadsheet model is essentially both a Level 2 and Level 3 model in one tool. If the user relies only on the default assumptions in the model, it more closely resembles a Level 2 application. If the user takes advantage of the advanced features of the model, it more closely resembles a Level 3 application.

Moreover, the Level 2 portion of the model yields simplified arrival and departure priority capacities as outputs, which the user must combine to estimate a total hourly capacity. By applying the advanced features (or Level 3) of the model, the user can achieve a more realistic and balanced capacity result.

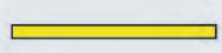
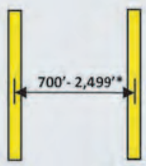
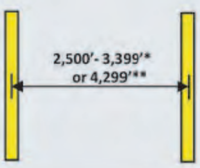
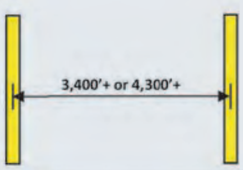
An example of a Level 2 model result for a single-runway configuration is shown on Figure 4-3.

The Level 2 output for VMC in this example shows the hourly arrival-priority capacity to be a mix of 33 arrivals and 14 departures. The departures-only hourly capacity is shown to be 52 departures. In VMC, the default hourly arrival-priority capacity, based on the default settings and the user-specified fleet mix and airfield conditions, results in an operational mix of 70% (33) arrivals and 30% (14) departures, for a total of 47 operations, which is the maximum hourly capacity in a mixed operations situation.

In the example given in Figure 4-3, notice that the hourly IMC total mixed operations capacity of 54 operations is greater than the hourly VMC total mixed operations capacity of 47 operations. When such an anomalous result occurs, it is because the larger separation requirements between arrivals in IMC allow more aircraft to depart in the gaps between arrivals. More importantly, it is a clear indication that the user must gap arrivals to let aircraft depart to increase VMC capacity, because any operations that can take place in IMC can take place in VMC. Such gapping is allowed in the Level 3 application of the Airfield Capacity Spreadsheet Model.

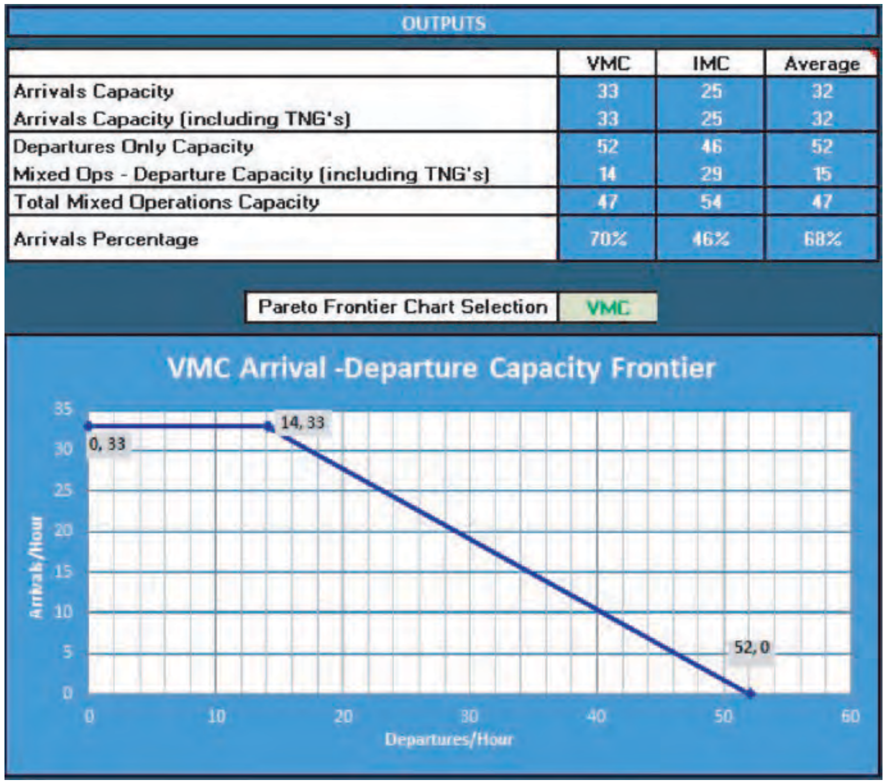
In the Level 3 environment, the user could adjust the aircraft performance parameters and make use of the advanced features of the model to arrive at an appropriate and balanced hourly capacity with 50% arrivals and 50% departures. Adjusting the gap spacing buffer in Level 3 is the primary mechanism used to achieve a balanced or specific operations mix. Figure 4-4 illustrates the output for the same single-runway configuration used for the Level 2 example, but with Level 3 inputs adjusted to balance the operations mix between arrivals and departures.

The Level 3 output for VMC in this example shows the arrival-priority capacity to be 33 arrivals with the departures-only capacity still shown to have an hourly capacity of 52. The balanced mix is essentially 28 arrivals and 27 departures, or 55 total operations, which results because the gap spacing is adjusted to allow for more departures between arrivals. Also note that the VMC capacity of 55 is now greater than the IMC capacity of 52, as appropriate.

General Runway-Use Configurations	New Aircraft Group Mix Percentages							Hourly Capacity Operations/Hour		Annual Service Volume
	A	B	C	C	C	C	D			
	S-S	S-T	S+	L-TP	L-J	L-757	H	VFR	IFR	Operations/Year
1.) Single Runway 	100%	0%	0%	0%	0%	0%	0%	90	66	223,000
	25%	50%	25%	0%	0%	0%	0%	74	62	213,000
	5%	20%	20%	25%	25%	5%	0%	63	56	206,000
	0%	5%	10%	10%	65%	5%	5%	62	50	209,000
	0%	0%	5%	5%	55%	5%	30%	60	48	225,000
2.) Dual Parallel Runways 	100%	0%	0%	0%	0%	0%	0%	180	66	378,000
	25%	50%	25%	0%	0%	0%	0%	144	62	275,000
	5%	20%	20%	25%	25%	5%	0%	104	56	242,000
	0%	5%	10%	10%	65%	5%	5%	96	84	352,000
	0%	0%	5%	5%	55%	5%	30%	88	72	353,000
3.) Dual Parallel Runways 	100%	0%	0%	0%	0%	0%	0%	180	80	389,000
	25%	50%	25%	0%	0%	0%	0%	152	76	386,000
	5%	20%	20%	25%	25%	5%	0%	128	76	314,000
	0%	5%	10%	10%	65%	5%	5%	124	84	380,000
	0%	0%	5%	5%	55%	5%	30%	120	76	385,000
4.) Dual Parallel Runways 	100%	0%	0%	0%	0%	0%	0%	180	132	447,000
	25%	50%	25%	0%	0%	0%	0%	152	124	435,000
	5%	20%	20%	25%	25%	5%	0%	128	112	417,000
	0%	5%	10%	10%	65%	5%	5%	124	100	419,000
	0%	0%	5%	5%	55%	5%	30%	120	96	450,000
5.) Intersecting Runways 	100%	0%	0%	0%	0%	0%	0%	94	66	232,000
	25%	50%	25%	0%	0%	0%	0%	86	62	224,000
	5%	20%	20%	25%	25%	5%	0%	74	56	214,000
	0%	5%	10%	10%	65%	5%	5%	84	62	270,000
	0%	0%	5%	5%	55%	5%	30%	82	62	298,000

Source: Landrum & Brown.

Figure 4-2. Level 1 model example—sample lookup table.

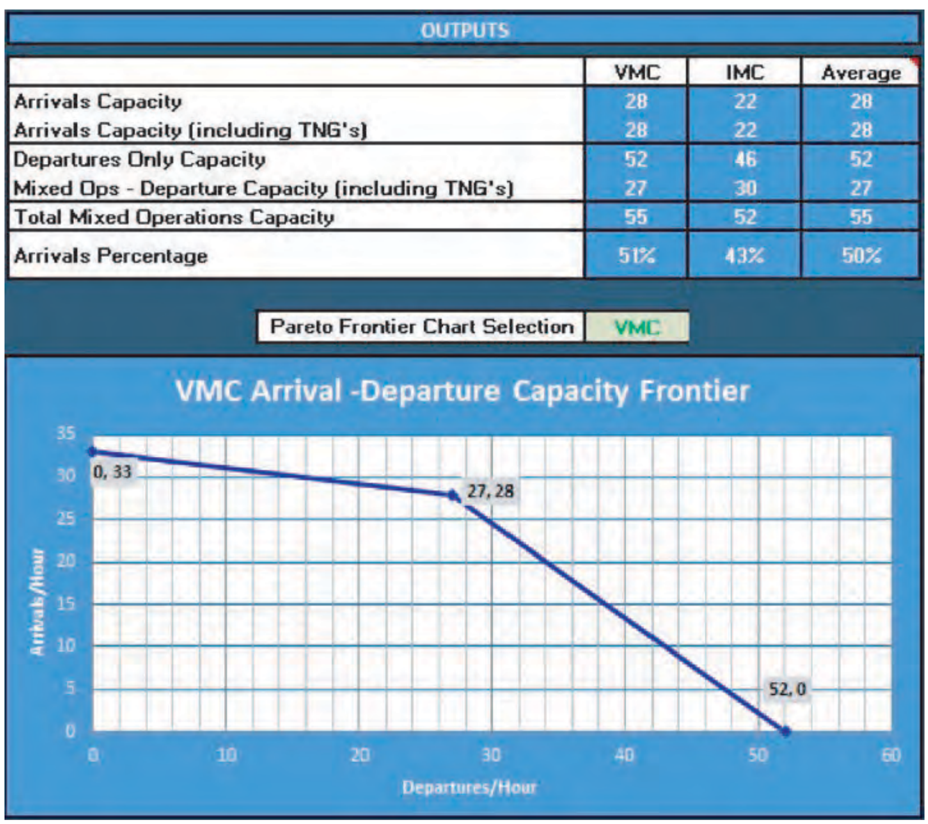


OUTPUTS

	VMC	IMC	Average
Arrivals Capacity	33	25	32
Arrivals Capacity (including TNG's)	33	25	32
Departures Only Capacity	52	46	52
Mixed Ops - Departure Capacity (including TNG's)	14	29	15
Total Mixed Operations Capacity	47	54	47
Arrivals Percentage	70%	46%	68%

Source: Landrum & Brown.

Figure 4-3. Level 2 model example—default outputs.



OUTPUTS

	VMC	IMC	Average
Arrivals Capacity	28	22	28
Arrivals Capacity (including TNG's)	28	22	28
Departures Only Capacity	52	46	52
Mixed Ops - Departure Capacity (including TNG's)	27	30	27
Total Mixed Operations Capacity	55	52	55
Arrivals Percentage	51%	43%	50%

Source: Landrum & Brown.

Figure 4-4. Level 3 model example—balanced outputs.

Testing and Validating the Airfield Capacity Spreadsheet Model

During the development of the Airfield Capacity Spreadsheet Model, comparison testing was conducted against actual data from FAA's Aviation System Performance Metrics (ASPM) database and capacity estimates and the lookup tables in the 2012 Capacity Benchmark Report, and *runway*Simulator. Throughout the process of validating the spreadsheet model, assumptions were adjusted and features were added to the calculation process to resolve some of the differences between the capacity estimates derived for the test airports using the spreadsheet model and those derived using the other methods.

Several scenario test cases were modeled and the results were compared against single, dual parallel, and intersecting runway configurations at San Diego International Airport, Fort Lauderdale-Hollywood International Airport, and LaGuardia Airport, respectively. The testing process required the use of consistent input parameters based on data from the ASPM database, ATCT data, and assumptions on operational practices based on knowledge of the airport operations. Results of this testing effort are shown in Table 4-1.

Table 4-1. Commercial airport model result comparison.

Airport	Runway Layout	Capacity Estimation Method	Fleet Mix	Maximum Hourly Capacity	
				VMC	IMC
San Diego International Airport (SAN)	Single runway	AC 150/5060-5	81-120% (C+3D)	55	53
		2012 Benchmark	N/A	57	48
		*runway*Simulator	4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy	60	52
		Airfield Capacity Spreadsheet Model	***4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy***	***60***	***54***
Mineta San José International Airport (SJC)*	Closely spaced dual parallel runways	AC 150/5060-5	81% to 120% (C+3D)	105	59
		2012 Benchmark	N/A	N/A	N/A
		*runway*Simulator	*18% Small-S, 3% Small-T, 76% Large-Jet, 3% Heavy*	68	50
		Airfield Capacity Spreadsheet Model	***18% Small-S, 3% Small-T, 76% Large-Jet, 3% Heavy***	***68***	***48***
New York LaGuardia International Airport (LGA)	Intersecting runways	AC 150/5060-5	81% to 120% (C+3D)	76	59
		2012 Benchmark	N/A	86	74
		*runway*Simulator	4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy	76	64
		Airfield Capacity Spreadsheet Model	***4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy***	***78***	***66***
Fort Lauderdale–Hollywood International Airport (FLL) †	Dual independent parallel runways	AC 150/5060-5	81% to 120% (C+3D)	111	70
		2012 Benchmark	N/A	74	56
		*runway*Simulator	4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy	68	52
		Airfield Capacity Spreadsheet Model	***4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy***	***64***	***56***

* Considers only Runway 12L-30R and Runway 12R-30L; Runway 11-29 not considered in analysis.

† Considers existing runway configuration of one runway open to all aircraft types and one runway used by small aircraft only.

Table 4-2. Small airport model result comparison.

Airport	Runway Layout	Percent Touch-and-Go Operations	Capacity Estimation Method	Fleet Mix	Maximum Hourly Capacity VMC	Maximum Hourly Capacity IMC
Small recreational airport	Single runway	50%	AC 150/5060-5	0% to 20% (C+3D)	98	59
			Airfield Capacity Spreadsheet Model	***100% Small-S***	***90***	***66***
Small executive airport	Single runway	40%	AC 150/5060-5	21% to 50% (C+3D)	74	57
			Airfield Capacity Spreadsheet Model	***25% Small-S, 50% Small-T, 25% Small+***	***74***	***62***

Validation of the Airfield Capacity Spreadsheet Model outputs showed acceptable and comparable results in hourly capacity between the spreadsheet model and *runway*Simulator (e.g., 62 operations per hour versus 59 operations per hour is regarded as an acceptable variation). The spreadsheet model produces an output that is more in line with a maximum capacity because the calculations are based on minimum separations. The results from the model can be adjusted or reduced by approximately 10%, as in the *runway*Simulator observations, to represent typical actual hourly flow rates that occur in a busy or peak period.

The Airfield Capacity Spreadsheet Model outputs also were compared to the AC lookup table in five cases, as summarized in Table 4-2. A new sample lookup table in the model was prepared using the assumptions outlined in the advisory circular as much as possible for a valid comparison. The biggest differences were in the IMC/IFR calculated results, where the spreadsheet model results were typically 10% higher (and more than 20% higher in a few instances) than the capacity values in the AC.

In summary, the hourly capacity counts were within the "10% or less" variance range and in many cases were nearly the same. The differing results may be attributed, in part, to the fleet mix allocation chosen for the spreadsheet model to represent five standard cases of varying aircraft types. The AC provides a range of fleet mix percentages but does not specify the actual fleet mix, whereas the spreadsheet model uses a specific set of fleet mix percentages. As such, the varying results observed are considered to be acceptable given the possible differences in assumptions and fleet mix specifications.

Overall, during testing the results from the Airfield Capacity Spreadsheet Model compared favorably with the other capacity estimates, and were found to be within a reasonable range. The variances can be understood in terms of the potential differences that could result from how the input assumptions are specified in each methodology. The Airfield Capacity Spreadsheet Model is presented as a prototype and, with future development, could be improved to provide the user even more ability to customize inputs so that it would also apply to more complex airfields.

Limitations

Although the spreadsheet model provides for significant input flexibility for a variety of parameters, as noted previously, if the airfield configuration is not included in the model or the airfield is operated in many different configurations, then the Airfield Capacity Spreadsheet Model would not reflect a total combined hourly capacity. The model's results present the following information for VMC, IMC, and an average weather condition:

- Arrivals-only capacity (with and without touch-and-go activity)
- Departures-only capacity (with and without touch-and-go activity)
- Total mixed operations

The spreadsheet model does not directly allow for the results to be combined to reflect the capacities for different arrival-departure ratios (or percentages of arrivals) over the course of the day.

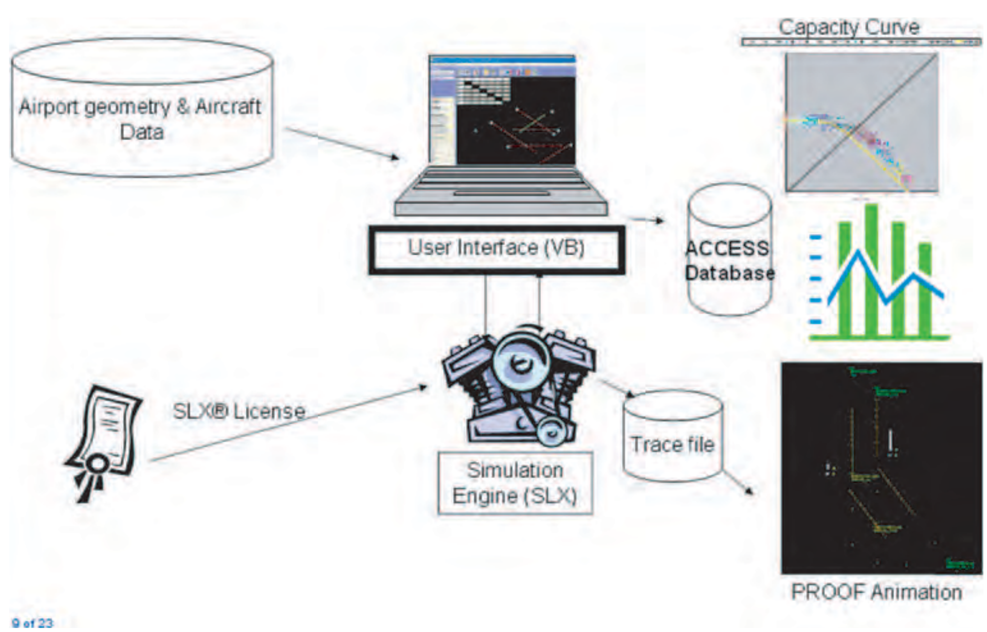
The Airfield Capacity Spreadsheet Model also does not allow some of the features of detailed simulation modeling, such as importing flight schedules or ASPM data.

Suggestions for Further Work

The Airfield Capacity Spreadsheet Model presents a first step toward a simplified, more transparent version of the ACM with more flexibility than currently provided by the methodologies in the AC. With additional resources, the spreadsheet model could be expanded to allow for additional user inputs to depict more airfield operational conditions. It should be noted that a more detailed version of the spreadsheet model would also require the user to input significantly more data and have more knowledge of the airfield's operating conditions.

Newly Available Level 4 Model—The MITRE *runway*Simulator

The Level 4 model examined in this research project was the MITRE *runway*Simulator (Figure 4-5). This level of sophistication reflects models that provide the flexibility of simulation but are easier to use and are intended to estimate throughput capacity rather than aircraft delay.



Source: MITRE Corporation.

Figure 4-5. Schematic of runway*Simulator's components.*

The *runway*Simulator is rapidly becoming FAA's model of choice for evaluating current airfield capacity. For example, MITRE is using the model in updating (1) FAA's *Airport Capacity Benchmark Report* (to be released in 2012), and (2) the Future Airport Capacity Task 3 (FACT 3) Study, "Capacity Needs in the National Airspace System: An Analysis of Airport and Metropolitan Area Demand and Operational Capacity in the Future."

The 2010 version of *runway*Simulator was examined for purposes of this guidebook. The model is currently being reprogrammed in Java, primarily to improve usability and the user interface. It is expected that the 2012 version of *runway*Simulator will be more user-friendly and add some features while keeping the same core logic and functionality. The new version of *runway*Simulator is expected to be made publicly available in 2012.

Capabilities/Description

The *runway*Simulator software runs on a personal computer (PC) running Microsoft Windows and currently requires runtime licenses for SLX and Proof, available from Wolverine Software Corporation, which is used by the simulation engine. MITRE plans to eliminate this requirement for the separate SLX and Proof runtime licenses in the publicly available version of *runway*Simulator that is expected to be released later in 2012.

The *runway*Simulator has a graphical user interface (GUI) for users to enter inputs. Results can be viewed within the model, and can also be exported to Excel. Outputs include a Pareto frontier (arrival priority, departure priority, and balanced capacity), as well as runway use and throughput by aircraft type. The *runway*Simulator has a graphical module to enable viewing of an animation of the runway operations.

The *runway*Simulator has capabilities to import some input data, including runway layout, aircraft performance, and ATC separations, which reduce the data collection and reduction burden. However, the user must verify that certain default data are applicable to the local airfield layout and operating conditions.

Improvements and Differences from Previous Models

The *runway*Simulator model is designed to fill the gap between high-level analytical models and detailed aircraft delay simulation models like SIMMOD and TAAM. The *runway*Simulator provides the capability to estimate capacity at airports with complex airfields and unique operating procedures. Previously, the only capacity estimation method that could reliably account for specific runway dependencies, runway use restrictions, and close-in airspace constraints was a detailed simulation model designed to estimate delay (i.e., SIMMOD or TAAM). The *runway*Simulator reflects more unique operating procedures without the level of effort and input assumptions required for Level 5 aircraft delay simulation.

Recommended Uses/Applications

The *runway*Simulator provides for a Level 4 tool to estimate maximum sustainable throughput of complex airfield layouts. It was specifically designed for that purpose and future versions will be made available to the public. Therefore, the *runway*Simulator is recommended for use in estimating the hourly throughput capacity of a complex airfield, or in estimating the capacity for an airport with complex operating procedures. In particular, the *runway*Simulator should be selected over Level 3 or lower models when estimating capacity for airports having the following characteristics:

- Runway configurations that are not represented in the set of configurations available in the ACM, the AC, or the Airfield Capacity Spreadsheet Model

- Unique runway dependencies, approach procedures, or departure procedures
- Runways that can only be used by certain aircraft types because of runway length or noise abatement policies
- Limited departure fixes or headings that restrict operations
- Unique approach procedures that involve nonstandard dependencies between runway operations, such as Simultaneous Offset Instrument Approach (SOIA), Converging Runway Display Aid (CRDA), and others

Testing and Validating the runwaySimulator

The purpose of testing and validating the *runway*Simulator was to assess the reliability of its capacity estimates. The research team applied the model to 14 test cases, each defined in terms of an airport, runway configuration, and weather condition. Four large commercial airports were represented—Newark Liberty International Airport (EWR), LaGuardia Airport (LGA), San Diego International Airport (SAN), and Fort Lauderdale-Hollywood International Airport (FLL). These airports provide representative, busy, one- and two-runway airports where demand is at or near capacity during peak hours, but are less busy during other hours. They also provide a sampling of dual parallel and intersecting runway conditions, and include aircraft taxiing across runways. Three visibility conditions—VMC, Marginal VMC (MVMC), and IMC—are represented for each airport. Two different VMC configurations were tested for EWR and LGA, bringing the total tests to 14.

In these test cases, the research team compared the *runway*Simulator outputs with observed data. The source of the observed data was FAA's ASPM database. ASPM contains extensive operational data for major U.S. airports, including all four considered in the tests. Much of the ASPM data is aggregated into quarter-hour observations, by airport; such quarter-hour data include:

- Runway configuration
- Arrival and departure counts
- Called rates—airport arrival rates (AARs) and airport departure rates (ADRs)
- Cloud ceiling and visibility
- Estimates, based on flight plans and actual arrival and departure times, of arrival and departure demand

In addition to these quarter-hour data, the ASPM database includes data on individual flights, including departure and arrival airports, out-off-on-in (OOOI) times, scheduled arrival and departure times, and aircraft type. For this research project, individual flight data determined the fleet mix.

The research team obtained the aforementioned data for each of the four airports considered in the test cases, covering the 5-year period from August 1, 2006, through July 31, 2011. These data were then filtered to obtain observations that would be suitable for comparison with *runway*Simulator output. For a given test case, the first step was to collect the observed counts and called rates for the associated airport, runway configuration, and weather condition. Next, the quarter-hour observed counts were filtered and aggregated to obtain a set of hourly observations that met the following criteria:

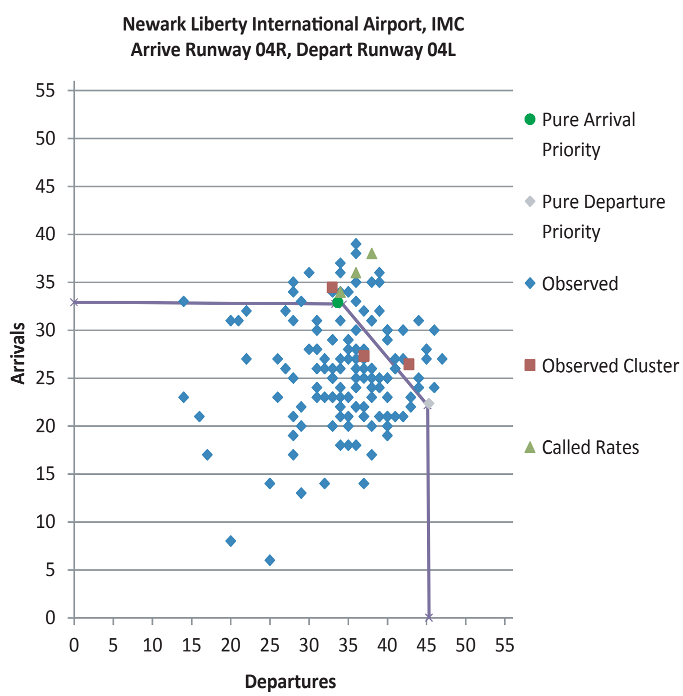
- Throughout the hour, the sum of the AAR and the ADR was within the normal range observed for that airport over the 5-year period.
- Demand throughout the hour was sufficiently high to justify the assumption that the airport was operating at or near capacity.
- The fleet mix among the cases was fairly consistent. (Among the sets of observations with similar fleet mixes, the set with the largest number of hourly observations was selected as the aircraft fleet mix for the test case.)
- Wind conditions did not appear to significantly reduce throughput.

The hourly observations that resulted from this procedure were expected to reflect situations in which (1) demand at the airport was sufficient for it to be considered operating at or near capacity, and (2) the aircraft fleet mix was fairly consistent. Substantial variability in hourly counts was still observed, however.

To facilitate comparisons with the *runway*Simulator output, the observed counts were clustered. A centroid was calculated for each cluster by averaging the arrival count and departure count for each cluster member. The objective was to identify clusters with centroids that reflected the realized capacity for the associated airport, configuration, weather condition, and fleet mix. The identified centroids were expected to be close to estimated capacities as represented by the Pareto curve obtained from the *runway*Simulator output, with inputs for the same conditions.

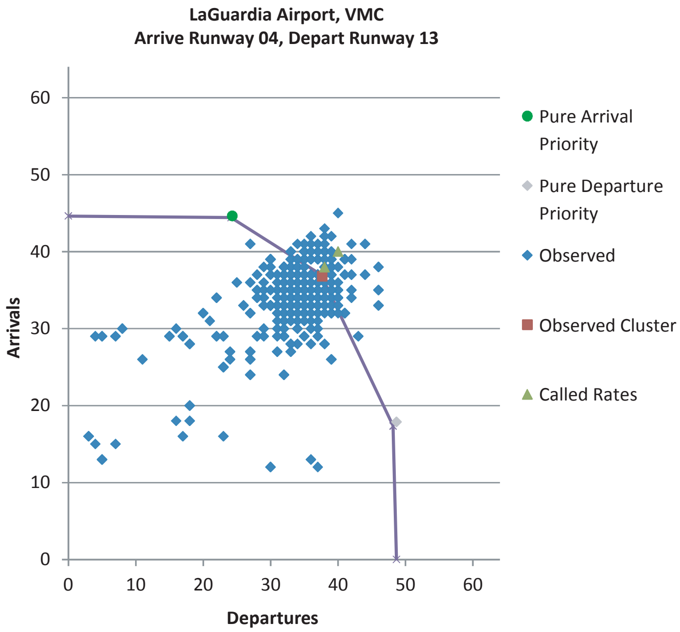
This analysis produced a series of plots, one for each test case. Figures 4-6 through 4-9 show plots for some of the test cases. Each plot contains the Pareto curve from the *runway*Simulator, along with observed counts from ASPM (after the filtering and aggregation process described above), cluster centroids derived from the observed counts, and the called rates (AARs and ADRs) for the given test case.

In some cases, such as EWR-IMC-4R|4L (Figure 4-6) and LGA-VMC-4|13 (Figure 4-7), there is good agreement between the cluster centroids and the modeled Pareto curves. In other cases, such as FLL-VMC-9L,9R|9L,9R (Figure 4-9) and SAN-VMC-27|27 (Figure 4-8), observed counts were lower than modeled capacity. The cases in which capacity exceeds observed throughput can be further subdivided based on the called rates. In the case of SAN-VMC-27|27, the called rate appears to be close to the Pareto curve defined by the cluster centroids. It appears that, in this case, throughput is limited by the called rate rather than capacity. On the other hand, in the case of FLL-VMC-9L,9R|9L,9R, the most common called rates are well outside the Pareto curve while the observed counts are well inside and far below the called rates. This result probably reflects a situation in which throughput is truly demand limited.



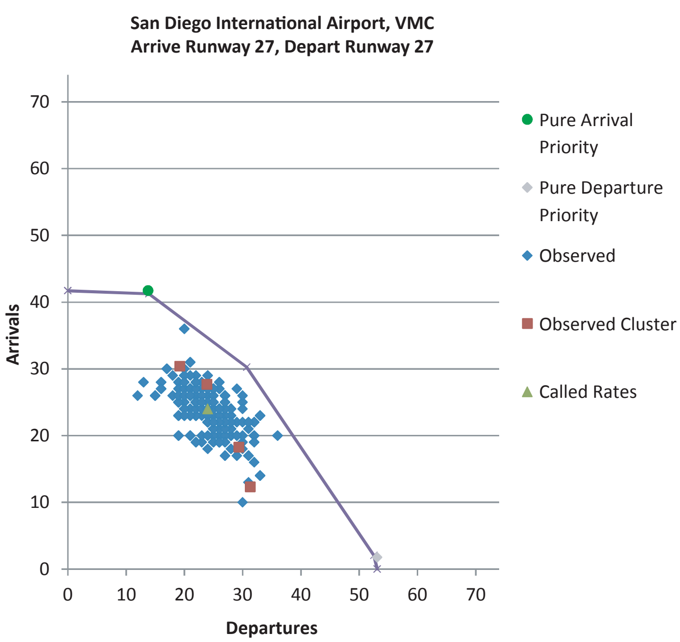
Source: University of California, Berkeley.

Figure 4-6. Capacity comparisons for Newark Liberty International Airport.



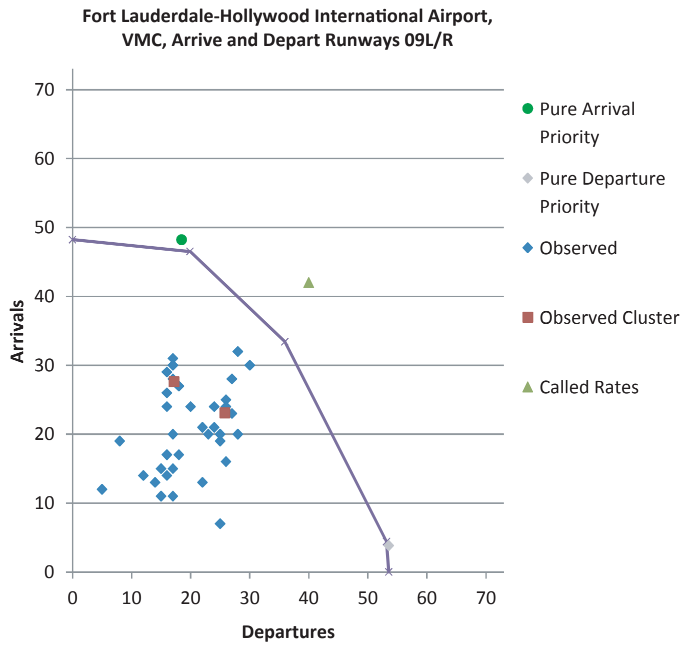
Source: University of California, Berkeley.

Figure 4-7. Capacity comparisons for LaGuardia Airport.



Source: University of California, Berkeley.

Figure 4-8. Capacity comparisons for San Diego International Airport.



Source: University of California, Berkeley.

Figure 4-9. Capacity comparisons for Fort Lauderdale–Hollywood International Airport.

Overall, the results of the analysis revealed that realized counts, even in periods of relatively high demand, were generally lower than the capacities estimated by the *runway*Simulator. To quantify this difference, the research team examined each selected cluster centroid and compared the total operations for that point with those for the point on the *runway*Simulator-generated Pareto curve with the same mix of arrivals and departures. Out of a total of 27 centroids, 24 had fewer operations than their associated Pareto points. The average centroid-to-Pareto point ratio was 0.84, with a range from 0.66 to 1.05. These ratios suggest that, as a rule of thumb, about 15% should be subtracted from the *runway*Simulator results to approximate operational counts that will be consistently realized in periods of high demand.

The above results indicate the difficulty of finding empirical observations in which throughput is truly limited by airfield capacity and, therefore, is an accurate representation of airfield capacity. This finding motivated an alternative approach to comparing the count data with *runway*Simulator results based on a statistical technique called censored regression. As applied in the research that led to this guidebook, censored regression is based on three main ideas:

1. Observed throughput is the minimum of demand and realizable capacity.
2. Realizable capacity is a random variable that varies significantly from time period to time period, even for a given configuration and visibility condition, because of changes in other factors, such as aircraft fleet mix, the arrival-departure split, and airspace fix/runway loadings.
3. The mean realizable capacity increases with demand, reaching full capacity only as demand becomes very high.

The first idea is widely accepted and central to the concept of capacity. The second and third ideas are more specific to airfield capacity and the ASPM demand metrics used in this research project. The ASPM data reveal that, for any given demand level, there is a substantial dispersion in throughput. As ASPM demand increases, the average throughput is observed to increase in a fairly continuous manner, albeit at a decreasing rate. This is most likely because ASPM demand is based on flight plans and, because of upstream disturbances, some demand does not materialize at the anticipated time. Demand must, therefore, be very high for it to be certain that enough flights will actually be available to arrive or depart during any given time period in order to make full use of the available capacity.

Based on the above assumptions and using the ASPM count and demand data—including observations in which demand was quite low—the research team developed a statistical model that estimates the limiting capacity that is realized when demand becomes very high. The coefficients of the model were estimated using the data for one VMC case and one IMC case for each of the four test-case airports, or eight test cases in all. This estimation approach took into account that operational capacity varies with arrival/departure mix and is typically greatest when the mix is about even. The estimated limiting capacity values were then compared with the corresponding values obtained from *runway*Simulator. Highlights of the results include the following:

- Capacities estimated using the statistical model averaged about four operations per hour, or 5% greater than *runway*Simulator predictions.
- Considering all eight test cases, the mean absolute error was ten operations per hour. Excluding FLL, which had poor results because of limited fleet mix data, the error decreased to seven operations per hour.
- The correlation between the statistically estimated and *runway*Simulator-generated capacities was 0.79 including FLL and 0.87 excluding FLL.

In conclusion, observed counts, even during busy periods featuring typical operating conditions, are often generally below capacities calculated by *runway*Simulator. This difference does not mean that *runway*Simulator is wrong. Rather, it means that airfield capacity is not the only factor limiting realized throughput as observable in the ASPM data on quarter-hour and hourly throughput values. As a rule of thumb, capacities calculated using *runway*Simulator should be reduced by 15% to approximate the actual counts that are representative of typical busy periods. At the same time, a statistical model that uses observed counts to predict throughput in very busy periods yields results that are fairly close and, in fact, generally exceed the capacity estimates from *runway*Simulator. In this latter case, it can be said that the model is consistent with the data that most closely approximate what the research team generally considers to be most representative of maximum sustainable throughput: namely, the capacities estimated using the statistical model.

Limitations/Suggestions for Further Work

It should be noted that *runway*Simulator 2010 was used for purposes of this research project. Some of the limitations discussed in this section may be resolved or improved with the release of *runway*Simulator 2012, which MITRE intends to make available to the public.

The *runway*Simulator installation process involves many steps, and the instructions provided do not identify all the possible problems the user may encounter during installation. Therefore, it may be difficult for the new user to complete the installation without assistance.

Operation of *runway*Simulator requires a trained user with sophisticated knowledge of the airport and operating procedures and with experience running computer simulation models. Employing all features in *runway*Simulator requires a user who also is knowledgeable about airfield and airspace operations and ATC procedures. New users require substantial training to use the model properly, even if they are familiar with other capacity evaluation techniques.

The *runway*Simulator requires much more site-specific input data and assumptions than the Level 3 models. This data burden is somewhat reduced, given the ability to import runway geometry, aircraft performance, and aircraft separation data. However, these data must be verified to confirm that they reflect actual operating procedures at the airport. Because the model is fairly data-intensive, its proper use requires substantial coordination with the airport operations and air traffic specialists to fully understand the operations and dependencies.

The *runway*Simulator does not currently simulate landing-roll behavior. Instead, arrival runway occupancy times (AROTs) are a model input by aircraft type, and are applied based on a user-entered standard deviation. To more accurately depict the influence of runway exit locations on runway occupancy times, it would be preferable to incorporate a landing-roll simulation module within the model. Until recently, *runway*Simulator 2010 had two modes for modeling AROTs. The first was to use an underlying trajectory landing-roll model, which incorporates aircraft performance parameters for touchdown speed, deceleration, and exit speed. The second was to draw an AROT from a user-specified distribution and to re-compute the deceleration parameter that would realize it. Both modes had arrivals exiting at modeled exit locations. The version of *runway*Simulator tested in this research uses a single mode whereby only the drawn AROT applies and exit locations are ignored. The anticipated 2012 version of *runway*Simulator will support the two modes again: (1) the underlying trajectory landing-roll model, which will use exits, and (2) drawn AROTs, which will not.

Finally, the *runway*Simulator is not yet very user-friendly; its user interface is complex, and its input stream is not transparent. It would be helpful if the user could easily review and make changes to the inputs. It is not always clear to new users when they can simply save the changes in the settings and when they must rerun the automated rule-generation feature referred to as the "Xbox." In addition, users may hesitate to change the settings because not enough instruction is given on the consequence of the changes.

Documentation supporting the *runway*Simulator is limited. It is recommended that a detailed user's manual be developed to accompany the 2012 version of the model when it is made publicly available.

New Guidance on Specialty Cases

Every airport has unique considerations that are important to reflect in a capacity analysis but may be challenging to account for explicitly in the available capacity analysis tools. It is often necessary to make adjustments outside of the model to reflect these considerations. More specific guidance is provided below for five specific situations that are commonly encountered:

1. Absence of a full-length parallel taxiway
2. Effects of runway crossings
3. Effects of an ATCT
4. Effects of staggered runway thresholds
5. Effects of aircraft-specific runway use restrictions

Absence of a Full-Length Parallel Taxiway

In the absence of parallel taxiway and connecting runway exits, aircraft must spend excessive time on the runway, which greatly reduces the effective capacity of the runway. The precise reduction depends on the presence or absence of intermediate taxiways that pilots can use to either access or exit the runway. Therefore, the effect on capacity is very site-specific.

In such circumstances, runway capacity is generally driven entirely by the required runway occupancy times of the aircraft operating on the runway. These runway occupancy times can be defined as follows:

- **AROT** begins when an arriving aircraft passes over the runway threshold and ends when it exits the runway. Without an available parallel taxiway, AROT includes time for the aircraft to taxi to the end of the runway, turn around, and taxi back on the runway until it reaches one of the centrally located taxiways leading to the aircraft parking ramp.
- **DROT** (departure runway occupancy time) begins when a departing aircraft begins to taxi to the end of the runway and includes the time it takes for the aircraft to turn around, complete its takeoff roll along the runway, and clear the opposite end of the runway.

Typical runway occupancy times are in the range of 40 to 60 seconds for arrivals and 30 to 45 seconds for departures. With no parallel taxiway, however, runway occupancy times can be as long as 4 to 6 minutes, depending on the locations where aircraft access and exit the runway and the location of the ramp. In extreme situations, the airfield capacity of a runway with no parallel taxiway can be as little as 15 to 20 operations per hour even when one or two intermediate entrances/exit points connect the runway to the ramp.

Unusually long runway occupancy times can be entered into any Level 2 through Level 5 analytical or simulation model that accepts AROTs and DROTs as inputs. For example, the effects of long runway occupancy times presented in Table 4-3 were estimated using the ACM. The table shows example calculations for estimating airfield capacity based on measured values of AROTs and DROTs for a hypothetical single runway with no parallel taxiway and one intermediate connection between the runway and the ramp.

These long runway occupancy times are the primary determinant of hourly runway capacity, and their effects on capacity also can be estimated outside of any model, using the tabular approach described in the notes following Table 4-3.

The Airfield Capacity Spreadsheet Model allows for up to a 50% reduction in estimated capacity where there is a partial taxiway or no parallel taxiway (see Figure 4-10). Essentially, the calculated capacity in the model may be halved if the runway must also be used as a taxiway for

Table 4-3. Estimated hourly runway capacities with no or partial parallel taxiway (sample calculations).

	Air Carrier and Air Cargo Aircraft Operations			
	Runway Occupancy Times (minutes)			Hourly Runway Capacity
Runway Configuration	Arrivals	Departures	Length of Arrival-Departure Cycle	
Flow direction A	6.0	2.0	8.0	15
Flow direction B	1.5	5.5	7.0	17

(1) Measure the approximate aircraft taxiing distance between completion of its landing rollout and exiting the runway, or between entering the runway and the beginning of its takeoff roll.
(2) Convert that distance into taxiing time by dividing the taxiing distance derived in Step 1 above by a reasonable average taxiing speed (e.g., 15 to 20 miles per hour).
(3) Add to the taxiing times derived in step 2 above either the landing rollout time (about 40 to 50 seconds) for arrivals, or runway clearance time (approximately 30 to 40 seconds) for departures to obtain the total AROT or DROT for each type of movement.
(4) Add the resulting runway occupancy times for arrivals and departures together to obtain a total arrival-departure cycle time (in minutes).
(5) Obtain the hourly runway capacity estimate by dividing the total arrival-departure cycle time into 60 minutes per hour, then multiplying by 2 to derive the total arrival and departure capacity, as shown in the right-hand column.

Source: LeighFisher.

Source: Landrum & Brown.

Figure 4-10. Level 3 options for specifying type of parallel taxiway.

the clearance of arrivals and departures. A factor of 1 is used with a full parallel taxiway, a factor of 0.7 is used with a partial taxiway, and a factor of 0.5 is used when no parallel taxiway exists. The model makes use of this reduction factor only in the single-runway configuration; otherwise, it is assumed that an adequate taxiway system is standard for dual parallel-runway systems or larger.

In addition, in the single-runway configuration model, the user can either (1) use the default runway occupancy times and select the type of parallel taxiway (which triggers the reduction factor), or (2) apply calculated or known runway occupancy times that result from not having a full-length parallel taxiway, which would alleviate the need to apply the capacity reduction factors. Known runway occupancy times based on the actual runway/taxiway/exit system would consider all factors and would likely yield much longer runway occupancy times for use in the model, similar to the example in Table 4-3.

Effects of Runway Crossings

Aircraft taxiing across an active runway take time away from the runway's primary purpose of accommodating arrivals and departures. Certain large natural gaps may occur in operations on a particular runway (e.g., because of required wake turbulence separations behind heavy jets or B-757 aircraft). Such gaps may permit one or more aircraft to cross the runway without affecting capacity. However, any gaps that do not permit such crossings will reduce the time available for the runway to be used for arrivals and departures. In addition, the use of multiple runway-crossing points is a common way for air traffic controllers to mitigate the adverse effects of runway crossings at airports that have significant numbers of runway crossings.

Below is an approximate method for estimating the effects of runway crossings on the capacity of the runway being crossed. This method reflects the major runway-crossing parameters that affect hourly runway capacity: namely, the number of crossings per hour, the number of crossing points, the required runway-crossing clearance time, and the frequency of large natural wake turbulence gaps behind heavy jets and B-757 aircraft. The notes following Table 4-4 describe the steps to be taken in this method.

Also shown in Table 4-4 are a number of sensitivity tests showing the effects of different assumptions regarding the number of crossing points, crossing clearance times, and percent of heavy jets or B-757s in the mix.

The methodology described in Table 4-4 yields only a rough approximation. This methodology is most appropriately applied in the case of aircraft crossing a departures-only runway, which is typically the case at major airports with significant runway-crossing issues. The methodology can be adapted, however, to situations in which aircraft are crossing an arrivals-only runway or a mixed operations runway, both of which occur less frequently than aircraft crossing a departures-only runway. Aircraft having to cross a mixed operations runway can be particularly difficult and disruptive.

The Airfield Capacity Spreadsheet Model applies the same basic logic as outlined in Table 4-4 (see Figure 4-11). In particular, it includes an input section that asks the user to state whether

Table 4-4. Estimated reduction in capacity because of runway crossings (see steps in methodology below table).

(1) Original Capacity Estimate	(2) Number of Crossings per Hour	(3) Number of Crossing Points	(4) Crossing Clearance Time (minutes)	(5) Percent Heavy Jets / B-757s in Mix	(6) Time Lost per Hour (minutes)	(7) Reduced Capacity Estimate	(8) Percent Capacity Reduction
52	20	1	0.50	15.0%	8.5	44.6	14.2%
52	20	2	0.50	15.0%	4.3	48.3	7.1%
52	20	2	0.75	15.0%	6.4	46.5	10.6%
52	20	2	0.50	0.0%	5.0	47.7	8.3%
52	20	1	0.50	0.0%	10.0	43.3	16.7%

(1) Estimate the capacity of the runway without adverse effects of crossings (Column 1).
(2) Estimate the expected number of runway crossings during the peak hour from an analysis of runway use and aircraft taxiing patterns (Column 2).
(3) Specify the number of crossing points. The effective number of crossings then is calculated as the number of crossings per hour (Column 2) divided by the number of crossing points (Column 3).
(4) Specify the estimated or measured runway clearance time (i.e., the time between issuance of a runway-crossing clearance to the pilot and when the aircraft clears the other side of the runway).
(5) Specify the percentage of heavy jets and B-757s in the aircraft fleet mix.
(6) Estimate the time lost per hour as a result of the runway crossings, which is equal to (effective number of runway crossings) x (clearance time per crossing) x (1 – the percent of heavy jets/B-757s).
(7) Multiply the original runway capacity by (60 minutes per hour – the time lost per hour) divided by 60.
(8) Compute the percent reduction in runway capacity by dividing (original runway capacity – reduced runway capacity) by original runway capacity.

Source: LeighFisher.

runway crossings occur or not. If runway crossings noticeably affect airfield capacity, the user inputs the average time (30 seconds, for example) the runway would be occupied to provide clearance for the crossing aircraft and the frequency of runway crossings in a design-hour. The model makes a general assumption that operations occur in the same manner as calculated, but runway availability is reduced from the maximum of 60 minutes.

For example, 20 crossings per hour at 30 seconds per crossing reduces the maximum available runway occupancy time for the operating aircraft fleet from 60 minutes to 50 minutes. This reduction would decrease the calculated runway capacity by nearly 17%. This same result would be obtained by inputting the same data in Table 4-4 and following Steps 1 through 8.

Effects of an ATCT on Airfield Capacity

An ATCT provides guidance for the movement of aircraft on and around an airport as they take off, land and taxi to or from the terminal area. The ATCT provides separation of aircraft on

Runway Crossing Delay ?	Yes	600
Average Crossing Delay	30	sec
Crossings during Peak Hour	20	Frequency

Source: Landrum & Brown.

Figure 4-11. Level 3 options for specifying runway crossings.

the ground as well as in the airspace within 5 nautical miles of the airport. Most of the world's airports are non-towered. Approximately 500 towered airports are in the United States (including both ATCTs operated by FAA and towers operated by private contractors).

At airports with an ATCT, the methods and default assumptions discussed in this guidebook are appropriate for use in calculating airfield capacity. However, for airports without an ATCT, additional factors must be taken into account when determining capacity. The main determinants of capacity at a non-towered airport are weather conditions, equipage, and characteristics of the traffic and pilot population.

A non-towered airport can be a challenging environment in which to evaluate airfield capacity because of the lack of ATC guidance and standard operating procedures. Although there are best practices for operating at non-towered airports, including special procedures for determining which runway to use, entering the traffic pattern, and announcing aircraft position and intent, very few legally mandated procedures exist. The precise effect of this lack of guidance and procedures on airfield capacity varies significantly from airport to airport, depending on the traffic level and level of sophistication of the aircraft and pilots operating at the airport. Moreover, little data are available on how many aircraft can actually use non-towered airports. By contrast, at towered airports, controllers must keep daily records of the numbers of aircraft landing and taking off at the airport.

The primary limitation on the capacity of a non-towered airport is the complex uncontrolled airport approach procedures for entering the traffic pattern, which require the pilot to overfly the airport to determine the appropriate runway use by observing the wind cone and number of aircraft in the pattern before maneuvering to enter the pattern as prescribed on the downwind leg. This maneuver is becoming more and more the exception, however, as more uncontrolled airports are being equipped with Automated Weather Observation Systems (AWOS) and Automated Surface Observation Systems (ASOS). Also, arriving aircraft typically call other aircraft already operating at the airport to determine the active runway or are able to speak to an individual at a fixed-base operator (FBO) or other facility on the ground that is monitoring the common traffic advisory frequency (CTAF) or the airport's individual frequency. In contrast, at a towered airport, controllers inform pilots which runways are in use and issue pattern-entry instructions. The ATCT controller is responsible for managing the number of aircraft in the traffic pattern and will instruct pilots to conduct full-stop landings if the traffic pattern becomes too full. In contrast, pilots operating at an uncontrolled airport have less ability to keep track of multiple aircraft in a flight pattern.

At an airport without an ATCT, capacity can be higher than an airport with an ATCT, assuming that the right equipment is in place for pilots to communicate. However, if a CTAF is not in place at a non-towered airport, capacity could be significantly lower than at an airport with an ATCT.

Touch-and-go operations generally remain within an airport's traffic pattern, which is the standard path followed by aircraft when taking off or landing while maintaining visual contact with the airfield and other aircraft in the pattern. In AC 90-66A, *Recommended Standard Traffic Patterns and Practices for Aeronautical Operations at Airports without Operating Control Towers,* FAA recommends traffic patterns and operational procedures for various aircraft activities and identifies regulatory requirements for non-towered airports. An ATCT provides the greatest capacity benefit when the proportion of touch-and-go operations is relatively low (i.e., when most aircraft are entering and exiting the traffic pattern), because entering the traffic pattern is the most complex self-separation task and, therefore, tends to limit the capacity of uncontrolled airports.

Effects of Radar on Airfield Capacity

The availability of en route or airport surveillance radar can significantly affect airfield capacity. At airports where the air traffic controllers cannot use radar separations for arriving or departing aircraft, procedural separation is used (e.g., the one-in, one-out rule or time-based separation requirements such as 10 minutes between successive arrivals). Procedural separations are many times larger than the minimum radar separation requirements.

Airspace and air traffic rules governing the spacing of arrivals and departures and the use of multiple runways, which are critical determinants of airfield capacity, all depend on the availability of radar for their execution. The ability of FAA to provide adequate separation between aircraft in the vicinity of an airport is dependent on the radar and communication capabilities of the system.

Effects of Staggered Runway Thresholds

Lateral separations between centerlines of parallel runways determine the relationships and ATC procedures required between the runways. At airports where the ends of two parallel runways are staggered, or offset from one another, the assumed centerline-to-centerline separation of the runways must be adjusted. Simultaneous arrivals to one runway and departures from a parallel runway require at least a 2,500-foot separation between runway centerlines. For simultaneous arrival/departure operations on staggered parallel runways, the required lateral separation of the runways depends on the magnitude and direction of the stagger. Staggered runways fall into two categories: (1) favorable stagger or (2) adverse stagger. For additional information, please refer to Chapter 3, Figure 3-25, of FAA AC 150/5300-13A, *Airport Design.*

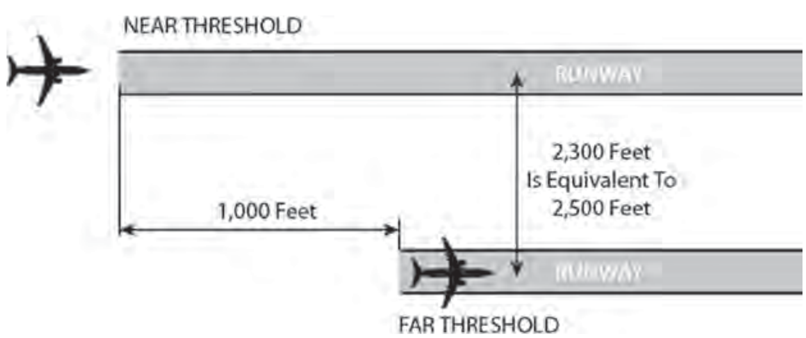
Favorable Stagger

When the runway thresholds are staggered such that the approach is to the near threshold, the requirement for 2,500 feet centerline-to-centerline separations between runways can be reduced by 100 feet for each 500 feet of threshold stagger, down to a minimum separation of 1,000 feet (or 1,200 feet for Airplane Design Group V or VI runways). This situation is shown in Figure 4-12.

Adverse Stagger

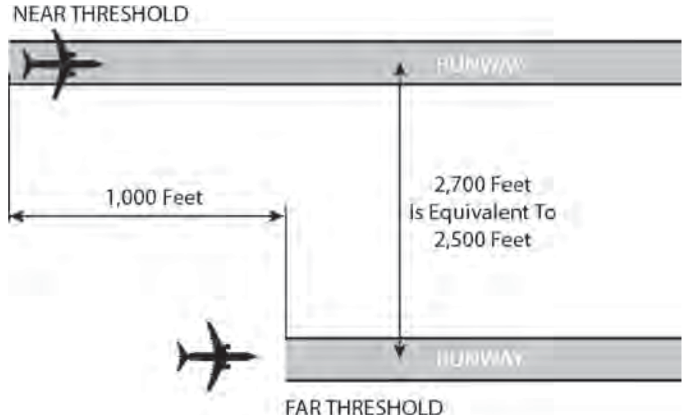
When the runway thresholds are staggered such that the approach is to the far threshold, the requirement for 2,500 feet centerline-to-centerline separation between runways must be increased by 100 feet for each 500 feet of threshold stagger. This scenario is shown in Figure 4-13.

When these minimum separation requirements between the parallel runway centerlines are satisfied, arrivals and departures can be assumed to be independent in IMC; otherwise, arrivals and departures should be assumed to be dependent.



Source: Presentation & Design Inc., based on FAA standards.

Figure 4-12. Favorable stagger showing reduction in required separation of 100 feet for every 500 feet of stagger.



Source: Presentation & Design Inc., based on FAA standards.

Figure 4-13. Adverse stagger showing increase in required separation of 100 feet for every 500 feet of stagger.

Effects of Aircraft-Specific Runway Use Restrictions

At many airports, and for a variety of reasons, the same aircraft fleet mix does not use all runways. When only small differences exist in the fleet mix using the different runways, the variations do not significantly affect overall airfield capacity. At some airports, however, large differences exist in the fleet mix using the different runways, typically because of noise abatement considerations or runway length. For example, certain runways cannot be used by jet aircraft because of adopted noise abatement flight procedures. Moreover, some commercial airports may designate a runway to be used exclusively by small general aviation aircraft.

At airports with these types of runway use limitations, the overall airfield capacity has to be estimated by analyzing the capacities of the individual runways and then deriving the overall capacity by enforcing aircraft fleet mix proportions (i.e., recognizing that certain runways may be underutilized because of the limitations on the aircraft types they can accommodate). Under such circumstances, it is particularly important to realize that the capacities of individual runways are not additive. For example, if a runway can accommodate only about 10% of the aircraft types operating at an airport, it will not contribute as much to airfield capacity as a runway that can accommodate any aircraft type.

If a runway is limited in the types of aircraft it can accommodate, the fact that its full capacity may not be usable must be taken into account, and adjustments must be made to reflect these restrictions in the estimate of the airport's overall airfield capacity. Only Level 4 and Level 5 models can explicitly account for such restrictions when estimating capacity. When using lower levels of modeling sophistication, manual adjustments must be made to account for the variations in aircraft fleet mix when aircraft classes are separated by runway. The goal of these manual adjustments is to make the calculations conform to the actual mix of aircraft using certain runways, so that a runway that is restricted to certain types of aircraft only contributes to capacity to the degree that aircraft in the mix can use the runway.

Consider two independent parallel runways, one restricted to Class A aircraft, and the other used by Class B, Class C, and Class D aircraft. To estimate the capacity of this airfield system, the capacity of each runway would be estimated, and then a manual adjustment would be made to enforce the mix. The first step would be to readjust, or normalize, the airfield mix to reflect the types of aircraft using each runway. Table 4-5 presents an example of runway-specific fleet mixes.

Table 4-5. Runway-specific fleet mix adjustment.

	Percent in Each Aircraft Class				
	A	B	C	D	Total
Airfield mix	18%	3%	76%	3%	100%
Runway 1 mix (Class A)	100%	0%	0%	0%	100%
Runway 2 mix (Classes B, C, D)	0%	4%	92%	4%	100%

Source: LeighFisher.

Table 4-6. Estimated hourly capacity by runway.

Runway	Hourly Runway Capacity (50% arrivals)
1	78
2	60

Source: LeighFisher.

Following the estimation of fleet mix by runway, capacity is estimated for each runway using that runway's fleet mix. The estimated capacities of Runways 1 and 2 in this example are shown in Table 4-6.

To calculate the appropriate overall airfield capacity for this example, the airfield fleet mix can be enforced by applying the following formula:

$$\text{Capacity} = \text{minimum}\left[\frac{c_1}{p_A}, \frac{c_2}{p_{B,C,D}}\right]$$

Where:

c_1 = *Capacity of Runway* 1 (*Class A only*)
p_A = Proportion of airfield mix that is made up of Class A aircraft
c_2 = Capacity of Runway 2 (Classes B, C, and D only)
$p_{B,C,D}$ = Proportion of airfield mix that is made up of aircraft in Classes B, C, and D

In the example described above, the overall hourly airfield capacity would be calculated as follows:

$$\text{Airfield capacity} = \text{minimum}\left[\frac{78}{0.18}, \frac{60}{0.82}\right] = 73 \text{ operations}$$

This calculation reflects the fact that Runway 1 would be underused, as only 18% of the aircraft mix is eligible to use the runway, while Runway 2 would be operating at full capacity. Moreover, Runway 1 would contribute only 13 operations (or 18%) to the total hourly airfield capacity.

Estimating Effects of NextGen on Airfield Capacity

The implementation of Next Generation Air Transportation System (NextGen) technologies and capabilities is expected to enable increases in airfield capacity through a variety of operational improvements. Many of these operational improvements are related to enabling multiple required navigational performance (RNP) approach procedures where multiple instrument landing system (ILS) approaches cannot be conducted today. In particular, these RNP approach procedures are expected to have the following benefits:

- Potential for more simultaneous movements and, therefore, greater capacity
- Reduced pilot and controller workload
- Reduced aircraft separations and obstacle-clearance standards
- More efficient horizontal and vertical profiles resulting in reduced fuel consumption and emissions

One of the core technologies of NextGen is the GPS-based Automatic Dependent Surveillance-Broadcast system being implemented today in the United States. This surveillance system is expected to ultimately supplement or replace existing legacy radar systems in the en route and terminal area airspace, because it will display aircraft position more accurately and enable a reduction in the achievable average separations between aircraft.

NextGen technologies and operational improvements will be gradually phased in as more airlines equip their aircraft and more enabling ATC rule changes and flight procedures are implemented. The precise timing and benefits of these NextGen operational improvements are not well defined, but they are expected to be implemented over time, with the most significant benefits occurring in the long term.

Nevertheless, FAA and the NextGen Joint Planning and Development Office have sponsored many airfield and airspace capacity studies aimed at estimating the capacity benefits of NextGen. In most of these studies, specific assumptions have been developed for several of the parameters commonly used in airfield capacity and simulation models.

For example, the NextGen operational improvements mentioned above are typically represented by (1) a reduction in the statistical spacing buffer used in these models; (2) a reduction in the minimum required aircraft separations, particularly in IMC; and (3) the ability to conduct more simultaneous movements on a given set of runways.

Assumptions regarding statistical spacing buffers have long been used to estimate the benefits of future ATC technologies. In analyzing airfield capacity, the spacing buffer generally is assumed to be represented by a standard deviation of 18 seconds in the ability of controllers to deliver aircraft to the final approach. In recent analyses conducted for the NextGen Joint Planning and Development Office, this spacing buffer was assumed to be reduced to about 12 seconds in the near term, and to about 6 seconds in the far term, where near term and far term are not precisely defined. The update of the FAA's *Airport Capacity Benchmark Report* for 2012 is expected to assume a reduced spacing buffer of 16.5 seconds for estimating airfield capacities for certain runway ends to represent recent implementation of the Traffic Management Advisor. The Traffic Management Advisor is a tool used in many FAA Air Route Traffic Control Centers (ARTCCs) and terminal radar approach controls (TRACONs) to sequence and schedule aircraft movements. This reduction in separation can only be applied to certain runway ends.

In certain other analyses performed for the NextGen Joint Planning and Development Office, analysts have assumed a reduction in IMC separation requirements of 1 nautical mile, reductions in AROTs and DROTs of 5 to 10 seconds, and independent approaches to closely spaced parallel runways. As of yet, no official, agreed-upon set of operational improvements and assumptions exists for use in estimating the airfield capacity benefits of NextGen—and they may never be, because estimating the benefits of NextGen will remain an airport-specific challenge, depending on aircraft equipage, runway configuration, demand characteristics, and other factors. For the foreseeable future, it is expected that coordination with FAA will be needed to agree on relevant assumptions about NextGen capacity benefits.

CHAPTER 5

How to Select the Appropriate Airfield Capacity Model

Selecting the appropriate level of model sophistication is not as easy as a one-size-fits-all approach. Many factors contribute to the type of model that is best suited to analyze a particular capacity issue. This chapter is intended to guide a capacity analyst to the appropriate level of modeling sophistication by presenting a decision-support tool and describing additional considerations in selecting a level of modeling sophistication.

The guidance presented in this chapter is not intended to provide a definitive, unique answer to the question, "Which model should I use in a given situation?" Rather, it is intended to guide the user through the factors to be considered in making a reasonable choice for a given set of circumstances. Rarely is there only one answer as to which model should be used, and many factors can affect a decision that cannot be captured in a decision hierarchy. Nevertheless, the guidance contained in this chapter should help the reader narrow down the choices regarding which levels of modeling sophistication are appropriate to a reasonable set of options, any of which would be satisfactory.

Decision Factors

Selecting an appropriate level of modeling sophistication depends primarily on the purposes of the capacity analysis and the characteristics of the specific airport.

Purposes of Capacity Analysis: What's the Question?

What types of capacity changes need to be analyzed, and why are the changes being analyzed? The answers to these "what and why" questions will largely determine the specific capacity factors and issues that must be addressed.

In this chapter, the following types of capacity changes will be considered in relation to the ways they affect data requirements and the choice of model sophistication level:

- New runways and runway extensions
- New taxiways, aprons, or gates (holding bays, parallel taxiways, runway exits, etc.)
- Changes in flight procedures and navigational aids
- Noise abatement procedures (e.g., multiple versus single headings, aircraft type restrictions, etc.)
- Aircraft fleet mix and stage-length mix changes
- Runway crossings
- In-trail terminal airspace restrictions
- Changes in navigational aid critical areas
- Multiple instrument approach procedures and staggered instrument approach procedures
- Effects of airport traffic control towers (ATCTs)

- Changes in air traffic control (ATC) rules and procedures
- ATC workload and human factors (such as pilot proficiency)
- Next Generation Air Transportation System (NextGen) benefits of reduced aircraft separations and new airspace procedures

New Runways and Runway Extensions

The choice of the level of modeling sophistication to analyze new runways and runway extensions depends on (a) the complexity of the airfield, (b) the location and function of the new runway or runway extension, and (c) the purpose and anticipated benefits of the improvement. New runways present the most extensive capacity change that can occur at an airport. The capacity effect of new runways depends most on (a) orientation and dependence in relation to other runways (i.e., parallel, converging, intersecting), and (b) expected runway use (i.e., arrivals, departures, or mixed mode).

A runway extension generally only affects airfield capacity if it would result in a significant change in (a) how the runway is used, (b) what aircraft could use it, or (c) whether it results in or eliminates an intersection with another runway or some other capacity constraint. For example, if the extension transforms the runway from a general aviation runway to an air carrier runway, then capacity could increase significantly. However, if the extension simply allows a few larger aircraft to operate more safely or several long-haul international flights to use the runway in off-peak periods, then its effect on airfield capacity would probably be negligible. If the runway extension results in an intersection with another runway, capacity could be reduced if both runways are used in a particular wind or weather condition.

Below are some additional considerations for deciding on a level of modeling sophistication for evaluating the capacity changes associated with new runways and runway extensions:

- **Airfield Complexity.** For simple or complex airfields, the model sophistication level required to analyze the change in capacity primarily depends on the additional capabilities provided by the improvement. Ironically, the greater the change in capabilities, the less sophisticated the model needed to measure it. Analytical models typically are adequate for analyzing major changes, such as increasing the number of runways from one to two. On the other hand, adding a fourth or fifth runway to an already complex airfield would almost certainly require an airfield simulation analysis to determine the expected marginal increase in capacity.
- **Degree of Change.** In most capacity analyses, the change in capacity is the most critical factor; therefore, it often requires a more sophisticated model or a higher level of fidelity and refinement to appropriately measure *small* changes in capacity. Less sophisticated modeling tools are usually sufficient to measure large changes in capacity.
- **Location and Function of Runway Improvement.** The location and function of a proposed runway are the primary determinants of the additional capabilities that would be provided. If the proposed runway would be independent of the other runways, then its benefits might easily be estimated using a Level 3 analytical model. However, if the proposed runway would be dependent on the other runways, a more sophisticated level (e.g., Level 4) model may be required. Moreover, if the proposed runway would create additional runway crossings or a complex runway intersection, then a more sophisticated level model may be appropriate, particularly because most Level 3 analytical models do not explicitly account for the effects of taxiways and runway crossings. In cases where a new runway would be located far away from the existing runways and terminal building, a Level 5 model is typically required to measure the trade-off between increased capacity and increased aircraft taxiing times.
- **Purpose and Anticipated Benefits of New Runway or Runway Extension.** The modeling sophistication level required to evaluate the capacity change with a new runway or runway

extension also may depend on the purpose and anticipated benefits of the improvement, which, in turn, may determine the evidence the model must provide to convince stakeholders that the benefits of the improvement are at least as great as its cost. For example, there may be a need for convincing evidence that the benefit of the improvement is justified because it would require significant capital investment or it may have adverse environmental effects. In either case, a more sophisticated level of modeling may be required to provide that convincing evidence at a level of detail appropriate for a benefit-cost analysis (BCA).

New Taxiways, Holding Bays, and Runway Exits

Detailed airfield simulation modeling is the only method now available to measure the effects of many types of aprons and gates on airfield capacity. Current analytical models do not include gates and have only limited capability to evaluate holding bays. Most analytical models strictly address airfield capacity and do not take into account other airfield elements except through the assumptions of runway occupancy times and, possibly, aircraft separations. New aprons at smaller general aviation airports do not necessarily require modeling. Regional airport system plans would not likely require measurements of the effects of aprons, only of runways.

Analytical models provide the means to evaluate some of the effects of taxiways on runway capacity, especially the effects of runway entrances and exits and parallel taxiways. More discussion of the modeling of these elements is provided in Chapter 4 of this guidebook.

Changes in Flight Procedures and Navigational Aids

Changes in flight procedures can be evaluated using either analytical or simulation models. Such changes will affect the percent of time that particular procedures can be conducted, aircraft separation requirements, and the number of simultaneous movements that can be conducted.

The determining factor in choosing an analytical model versus a simulation model may depend primarily upon the effect of the flight procedures on the number of simultaneous movements, which, in turn, depends on the complexity of the airfield.

Changes in Noise Abatement Procedures

The effects of noise abatement procedures can be estimated using analytical models if the effects of such procedures can be defined in terms of increased or decreased in-trail separations, or significant changes in runway use. Otherwise, airfield simulation modeling may be needed.

For example, a noise abatement procedure may require turbojet aircraft to fly a long common path but allow turboprop and propeller aircraft to make immediate turns. The net effect of such a noise abatement procedure is complex and dynamic and would depend on how well controllers can sequence departures such that they avoid sending two successive turbojets to the same departure fix. Analyzing such effects may require a higher level of modeling sophistication than most analytical models can provide.

Aircraft Fleet Mix and Stage-Length Mix Changes

Analytical models should be sufficient to estimate the effects of a change in aircraft fleet mix on airfield capacity if that change does not significantly affect how the runways are used or what aircraft can use which runway. Such a change would be reflected primarily in how frequently certain aircraft-pair combinations occur and, therefore, the average time interval between operations.

A change in stage-length mix may affect runway use because the pilots of longer stage-length flights may request use of a longer runway. Unless the change in stage-length mix is significant, however, its effect on capacity is probably negligible and may not justify a higher level of modeling sophistication.

Changes in Runway Crossings

Airfield simulation modeling generally is required to reflect the effects of runway crossings on airfield capacity primarily because of the complex interactions between the aircraft arriving and/or departing on the runway and the aircraft trying to cross that runway. Changes in the frequency of runway crossings can be caused by addition or removal of runway crossing points, use of land and hold short operations (LAHSO), provision of end-around taxiways, and changes in runway use. Some analytical models are designed to evaluate simple runway-crossing scenarios, as described in Chapter 4, but they may not be adequate to evaluate crossings involving multiple runways.

In-trail Terminal Airspace Restrictions

The effects of in-trail terminal airspace restrictions can be estimated either implicitly using analytical models or explicitly using airfield simulation models. Only Level 5 simulation models enable the user to explicitly measure the controller's ability to sequence departures to minimize the effects of having to send two successive aircraft to the same restricted departure fix. Therefore, aircraft delay simulation models (Level 5) are preferred for this purpose if sufficient time and budget are available. Such models provide a more fine-grained analysis of the effects of such restrictions on airfield capacity and proposed improvements to mitigate those effects.

Changes in Navigational Aid Critical Areas

Navigational aid critical areas can affect capacity by restricting access to the runway. For example, an instrument landing system (ILS) glide slope critical area may encroach on the taxiway leading to the end of a departure runway. If the aircraft is held short of the critical area, it will take longer to taxi to the departure end of the runway to line up and wait or be cleared to take off, which, in turn, will increase the separation that controllers must provide between arrivals to release the departure between arrivals.

Analytical models can be used to measure such an effect by either (a) increasing the arrival-arrival separation required to release a departure between arrivals, or, equivalently, (b) increasing the required arrival-departure separation (i.e., the distance out from the threshold that an arrival must be in order to release a departure). Unless this distance is increased, the ability of controllers to clear departures between arrivals in an arrival-priority operating mode could be restricted.

Simulation models may be required if the effect of the navigational aid critical area is more complex or to explicitly measure the effect of the navigational aid critical area through assumptions regarding the additional aircraft taxiing distances and clearance times that the critical area would impose on departures. For example, to avoid having to hold departures short of an ILS glide slope critical area, controllers could, if advantageous, taxi aircraft across the runway to a parallel taxiway on the other side of the runway so that they can be more easily cleared onto the runway for departure. The effect of using such a runway crossing versus having to wait at the ILS hold line would have to be measured using a Level 5 simulation model.

Another possible effect of eliminating the need to hold departures short of a navigational aid critical area may be a change in runway use. For example, depending on the complexity of the airfield, controllers could make greater use of a runway for departures if the need to hold departures short of a navigational aid critical area were eliminated. In this case, Level 4 or Level 5 airfield simulation modeling may be required to estimate the capacity benefit of such an improvement.

Multiple Dependent and Independent Instrument Approach Procedures

A higher level of modeling sophistication, such as Level 4 and Level 5 airfield simulation modeling, would be preferable for estimating the effects of introducing a new multiple-approach procedure, such as a simultaneous offset instrument approach procedure or a dependent converging instrument approach procedure using a converging runway display aid.

Such improvements increase the complexity of an existing airfield operation to the extent that analyzing their benefits using analytical models becomes very difficult. In particular, modeling staggered instrument approach procedures can be very complex if the procedures require that standard wake turbulence separations be provided behind a heavy jet or a B-757.

Effects of Airport Traffic Control Towers

The effects of installing or removing an ATCT can be measured most easily through before-and-after analyses using an analytical model that would include appropriate assumptions about the changes in aircraft separations made possible with the ATCT.

Without the ATCT, aircraft would have to follow uncontrolled airport approach and departure procedures, relying on visual separation from the cockpit and pilots announcing their intentions over a universal communications (UNICOM) system. Although such uncontrolled airport procedures can be efficient, pilots operating at a busy uncontrolled airport tend to be very conservative in separating themselves from other aircraft.

With the ATCT, controllers can apply visual separation and provide clearances to land and take off, which generally results in shorter intervals between operations and greater runway use, thereby increasing airfield capacity. Except in rare cases, simpler techniques for evaluating airfield capacity, such as table lookup or simple analytical models, would be most appropriate. The use of airfield simulation models would typically not be justified unless the airport has a complex runway layout.

Changes in Air Traffic Control Rules and Procedures

Most changes in ATC rules and procedures can be analyzed using either analytical models or simulation models, depending on the complexity of the airfield being analyzed and other factors, such as those addressed in previous sections of this guidebook. Such changes usually affect the magnitude of aircraft separations or the degree of dependence between runway operations.

In the past, such changes have included (a) the ability to operate 2.5-nautical-mile spacing on final approach for runways on which average arrival occupancy times of 50 seconds or less can be demonstrated, (b) dependent ILS approaches with 1.5-mile staggered separations, (c) addition of divergent runway headings to runway ends which currently do not have them, and (d) restrictions on the ability of larger aircraft to overtake smaller aircraft on final approach to closely spaced parallel runways to avoid hazardous wake turbulence interactions. The first three of these changes could be analyzed easily using simpler analytical models, such as the FAA's ACM. The fourth change—restrictions on larger aircraft overtaking smaller aircraft on final approach—has been more difficult to analyze using the ACM because of the complex modeling required to measure the effects of the aircraft fleet mix on such a restriction. Therefore, the choice of model for analyzing such changes in ATC rules and procedures would depend on the complexity of the change under consideration and the complexity of the airfield layout.

Air Traffic Control Workload and Human Factors Restrictions (Including Pilot Proficiency)

Human factors are not very well represented in available analytical models or simulation models for evaluating airfield capacity. Sometimes, for an airport-specific procedure or restriction, an analyst can receive controller input on an average aircraft separation or acceptance rate to adjust the model separation minimums or associated buffers to reflect high controller workload. For example, conducting visual approaches to closely spaced parallel runways, where extensive voice communication is required on the part of the pilots and controllers, often is characterized as being driven by how fast controllers and pilots can talk.

Pilot proficiency is rarely modeled in terms of how it affects airfield capacity except in cases where pilot proficiency with the English language limits the ability of controllers at busy international airports to conduct visual approaches. Pilots who are not proficient in English generally will not accept a visual approach clearance. In the United States, visual approaches are almost universally accepted, except at large international airports where many pilots are flying foreign-flag aircraft. At most other international airports around the world, where ATC communications are conducted in multiple languages, visual approach clearances are not accepted or conducted at all.

NextGen Benefits of Reduced Aircraft Separations and New Airspace Procedures

The capacity benefits of anticipated NextGen operational improvements have been estimated using a variety of analytical and simulation models. Consistent with previous recommendations, the choice of model for evaluating these benefits depends primarily on the complexity of the airport operation and the complexity of changes associated with the NextGen operational improvement under consideration.

For example, Boeing recently used an analytical model to estimate the capacity increases at 35 airports associated with a set of operational improvements anticipated with NextGen.

At the other end of the modeling sophistication scale, researchers at NASA Ames Research Center have used the Airspace Concept Evaluation System (ACES) model to evaluate the effects of NextGen on the national airspace system (NAS). ACES is an agent-based, NAS-wide, non-real-time simulation model.

MITRE Corporation has been estimating the effects of NextGen technologies on airfield capacity using its *runway*Simulator, which is a Level 4 airfield capacity simulation model designed to estimate throughput using input parameters similar to those used in the ACM.

Members of the research team that developed this guidebook have estimated the effects on airfield capacity of various NextGen technologies using the ACM. In this modeling exercise, the primary parameter assumed to change as a result of NextGen technologies was the statistical spacing buffer applied to the minimum aircraft separation requirements. NextGen also was assumed to have an effect on runway occupancy times and certain minimum wake turbulence aircraft separation requirements. These same changes in parameters were used in modeling NextGen operational improvements for FAA and the Joint Planning and Development Office (JPDO), a cross-agency entity created in 2003 to manage the public-private partnerships that were designed to implement NextGen.

Airport Characteristics

The level of modeling sophistication appropriate for a particular application depends to a certain extent on the characteristics of the airport being analyzed. The following airport characteristics can affect the choice of modeling sophistication level:

- Level of capital investment and complexity of airport operations
- Types of activity at the airport
- Capacity issues to be addressed
- Airport size

Level of Capital Investment and Complexity of Airport Operations

Evaluations of airport improvements requiring significant capital investment or at airports with highly complex operations or airfield configurations typically justify using higher levels of modeling sophistication. In most cases, these conditions occur at larger airports rather than at smaller airports. However, this generalization does not always apply, such as when a complex issue needs to be addressed at a small airport that requires a high level of fidelity in the airfield capacity modeling to be able to distinguish the effects of small differences among alternatives.

Types of Activity at the Airport

Another airport characteristic that affects the choice of modeling sophistication level relates to the types of activity at the airport. In particular, the presence of high levels of training activity or wide ranges of aircraft types operating on the airfield affect the selection of an appropriate level of modeling sophistication. Instrument approach procedures in effect at the airport also influence the choice of an appropriate capacity evaluation technique.

Capacity Issues to Be Addressed

One of the most important factors affecting the selection of a level of modeling sophistication is the capacity issues to be addressed (i.e., the reasons for the analysis). For example, all master plans require some form of airfield demand-capacity analysis to examine the need for additional capacity at the airport. However, if airfield capacity is not known to be an issue at the airport, the level of modeling sophistication necessary to meet this master planning requirement could be minimal. In such cases, a simple methodology that uses the Level 1 lookup tables in AC 150/5060-5 (the AC) or the Airport Design Computer Program model may be sufficient to address this requirement. Similarly, state system plans typically do not address airfield capacity other than through a high level review of annual service volume (ASV) and comparison of annual operations to reveal potential capacity needs. However, some regional airport system plans are being developed primarily to mitigate capacity constraints caused by conflicts between airports in the region, and such plans could require a sophisticated Level 5 model to address specific capacity issues.

Airport Size

The size of the airport typically has a significant effect on the appropriate level of modeling sophistication. However, making a determination based on simple descriptive categories, such as large, small, commercial service, or general aviation, is not always appropriate. To determine the appropriate level of model sophistication, the size of the airport must be determined in terms of the types of facilities and amount and/or type of activity at the airport. At airports that may typically be referred to as small, the following factors have been identified as being relevant in determining the necessary level of modeling sophistication:

- **Presence or Absence of an ATCT.** An airport with an ATCT can likely accommodate a higher number of operations (hourly, daily, and annually) because the ATCT can provide pilots with information to maintain a safe and efficient flow of traffic. Without an ATCT, pilots rely on seeing each other and announcing their intentions using radio communication (UNICOM) to determine where other aircraft are in relation to the airport and the ability of the pilot to safely land the aircraft. Typically, airports without an ATCT are less busy from an operational perspective and the issue of capacity is one of perspective, as reliable data on actual operational activity are not available. The absence of an ATCT may be related to the limited operational activity at the airport, as less busy airports are not likely to be able to meet the FAA's criteria for establishing an ATCT.
- **Presence or Absence of Commercial (Air Carrier) Passenger Service.** Commercial passenger service can affect airfield capacity depending on the types of aircraft that provide service and the number of operations conducted by the commercial passenger airline(s). If passenger service is provided using a mix of small and larger aircraft, the capacity calculations are affected more than if the sizes of the aircraft are more homogeneous. A significant level of passenger service would also require taking into account airline schedules, parking areas, gates, and

other factors that may affect airfield capacity. Airports without commercial passenger service, referred to as general aviation airports, can still be served by a diverse aircraft fleet and may still require a Level 4 or Level 5 airfield capacity evaluation based on this fleet and the number of operations at the airport, particularly if airport taxiways and aircraft parking areas are an issue.

- **Presence or Absence of an Instrument Approach Procedure.** The lack of an instrument approach procedure limits airfield capacity, as activities are not considered that cannot be accommodated during conditions below visual approach minimums or basic visual flight rules conditions (i.e., when the ceiling is less than 1,000 feet or visibility is less than 3 miles). The AC lookup tables are based on specific assumptions regarding the presence of specific facilities and approach procedures. These include a precision approach (an instrument landing system is noted specifically), a full-length parallel taxiway, and a runway configuration. The lack of an instrument approach procedure may be related to limited operational activity at the airport, as less busy airports are not likely to be able to meet the FAA's criteria for establishing an instrument approach procedure.
- **Number of Annual Aircraft Operations.** The current process for evaluating airfield capacity for any specific time period requires comparing the number of operations to the calculated capacity for that period. Airports with a low number of aircraft operations compared to the calculated capacity for that period would not be identified as having a capacity issue and, therefore, would not require detailed analysis of airfield capacity. Even if the types of activity accommodated include a diverse range of aircraft types, a low number of annual aircraft operations likely indicates that airfield capacity is not an issue and that a low level of analytical modeling sophistication would be sufficient.
- **Number of Training or Touch-and-Go Operations.** Training or touch-and-go operations typically increase the operational capacity of an airport because the pilots conducting these operations have aircraft in the pattern continually ready to take off and land, and each touch-and-go counts as two operations: one landing and one takeoff. The AC Level 3 methodology specifically includes a factor related to the percent of training operations in total operational activity in calculating an hourly capacity and an ASV for the airport.

Additional Considerations

Certain additional considerations may override the general logic and hierarchy discussed in previous sections of this chapter. These additional considerations include the availability and adaptability of legacy models, time and budget constraints, availability of data, levels of stakeholder involvement in the capacity analysis, magnitude of investment, and the level of accuracy required to discern benefits versus costs.

Availability of Legacy Models and Risks of Updating Previous Modeling Efforts

If various models have been used for capacity analysis during previous planning projects, continuing to use such legacy models can reduce the time and cost required to complete a new analysis. Using a legacy model means it is not necessary to develop a new baseline model. Using a legacy model also avoids the need to calibrate the model, assuming that no significant changes at the airport would dictate a recalibration. It also maintains consistency in measures and methods for comparison with prior analyses. Using previously developed models, at least as a starting point, typically is most beneficial for simulation modeling that has a long start-up and calibration time.

Before deciding to use a legacy model, however, it is important to review the model to ensure that it is not erroneous and that any assumptions are still current. It should be verified that the model was calibrated properly. New data should be collected to refresh any needed inputs related to forecasts and demand patterns. A particular model or level of sophistication should not be selected solely because a legacy model is available. More important considerations are the capacity issue being analyzed, the time and budget available, and the factors affecting airfield capacity that need to be incorporated into the analysis.

Time and Budget Constraints

The available time and budget may limit the choice of a modeling sophistication level for the airfield capacity analysis. If time and budget resources are limited, analytical models or spreadsheets may be the most appropriate choice.

In many cases, an airport sponsor has only a short window for decision making, whether for policy decisions or funding decisions (e.g., to proceed further with a capital improvement). Such time constraints may dictate the use of less sophisticated models, even though other considerations would suggest a different choice. In such cases, it is not unusual to follow such analyses with more sophisticated modeling in support of further funding decisions, planning or design requirements, proof of concept, environmental analyses, or phasing plans.

Notwithstanding the guidance provided in this chapter for choosing an appropriate level of modeling sophistication, exceptions will always exist related to time and budget constraints.

Availability of Data

The data available to the capacity analyst can be a deciding factor in the level of modeling sophistication selected. Data may not be available for many reasons, including the following:

- The data may not exist or be recorded.
- The data may not be publicly available.
- The data may be too costly to acquire.
- The data may be too time-consuming to process.

For example, even if a non-ATCT airport is facing a complex capacity issue related to taxiways, it may not be feasible to construct a simulation model because of the lack of data regarding flight schedules and characteristics of operations. Or, at an airport with no scheduled passenger service, it may be difficult to calculate fleet mix, which eliminates many capacity analysis methods from consideration. However, default values often can be used in lieu of particular inputs in cases where data are unavailable or infeasible to obtain.

Figure 5-1 summarizes the data that are typically required for the various levels of modeling sophistication.

Figure 5-1. Choosing the level of modeling sophistication based on data availability.

See Chapter 3 for a discussion of the data requirements for each level of sophistication. A guide to data sources is provided in Appendix B of this guidebook.

Level of Stakeholder Involvement in the Capacity Analysis Process

For controversial or high-profile projects it may be necessary to work with agencies that are unfamiliar with the nomenclature or metrics used in airfield capacity evaluations (e.g., when conducting extensive public workshops or when providing briefings to elected officials). In such cases, graphic output ranging from simple diagrams and charts to animations of airfield/airspace options can aid in explaining (1) the issue that has led to a proposed improvement, (2) the purpose of the proposed improvement, and (3) the benefits to be derived from the proposed improvement. In these cases, the sophistication of the model tends to be less important than the ability to communicate the critical issues to the non-aviation community. However, it is important to be consistent with metrics previously reported for an airport (i.e., throughput capacity, annual capacity, or aircraft delay).

Magnitude of Investment

The magnitude of investment does not always correlate to the level of modeling sophistication needed. This correlation applies in some, but not all, situations. For example, some smaller changes in capacity may not be able to be distinguished and evaluated using anything except simulation modeling (e.g., the expected change in runway throughput with proposed taxiways or holding bays that enable improved departure staging and sequencing). At the same time, smaller investments may not warrant the use of expensive, high level simulation tools. For large-scale projects, especially those that are subject to FAA BCA requirements for Airport Improvement Program grant consideration, simulation modeling may be needed to provide the appropriate level of fidelity even if the magnitude of investment is relatively modest.

The more important determinant of required modeling sophistication is the expected change in capacity. For example, the changes in capacity expected from the addition of a new runway can easily be estimated with lower level models, tables, or spreadsheets. For an investment as large as a new runway, however, a higher fidelity level of modeling that includes simulation usually is recommended.

Level of Accuracy Required to Discern Benefits versus Costs

The level of accuracy is directly correlated to the level of modeling sophistication: as the level of modeling sophistication increases (and the more airport-specific data inputs are required), it is expected that the level of accuracy of the results would increase. The level of accuracy needed to discern benefits is project-specific. Often, smaller projects have a small margin of benefits, which requires a higher level of accuracy to be able to measure the benefits. On the other hand, large projects that provide a large change in capacity can be captured using analytical or other lower-level modeling techniques.

Notice that a high level of accuracy may not be required to discern the benefits of a project (e.g., the capacity increase associated with a new runway). A high level of modeling sophistication may be needed, however, because of the magnitude of the investment or because of other factors. Alternatively, the change in capacity of a small project (e.g., a departure sequencing hold pad) may be best measured using simulation, but the time and budget available for the analysis may preclude the use of the more time-consuming and costly simulations.

High-Level Matrix for Preliminary Screening of Levels of Modeling Sophistication

Figure 5-2 presents a high-level matrix of the major decision factors to be considered in choosing a level of modeling sophistication for a particular set of circumstances and conditions. This matrix is intended for preliminary screening purposes, and can be used in conjunction with the more detailed decision hierarchy described in the text.

Decision Hierarchy

The decision hierarchy developed as part of ACRP Project 03-17 supports an airport operator's decision-making process in selecting an appropriate method of capacity analysis. It is important to note that this decision hierarchy is not meant to provide a definitive answer, but instead should be used as a decision-support tool. For any capacity issue being analyzed, different levels of modeling sophistication could be used. Moreover, the decision-support tool provides only the recommended level of sophistication "in a perfect world." Exceptions and special circumstances will always exist that could dictate a different choice or that do not follow the logic presented in the decision hierarchy.

The decision hierarchy is intended to distinguish between the factors for which each level of sophistication can account, allowing a capacity analyst to identify the specific attributes of the capacity issue that would drive the use of a certain level of modeling sophistication. The distinguishing factors between one level and the next are presented in a hierarchy for a capacity analyst to consider in selecting the appropriate level of sophistication. The questions and characterizations of each level are meant to answer the question, "In a perfect world, which level of modeling sophistication should you use?" In many situations, however, multiple levels of modeling sophistication can be used.

The questions in the decision hierarchy are presented in Figure 5-3 and explained in more detail in Table 5-1.

Examples of Level of Modeling Sophistication Used in Airfield Capacity Case Studies

ACRP Project 03-17 included the preparation of 27 case studies of applications of airfield capacity analysis. These case studies were selected to include a wide-ranging sample of applications of capacity analyses and levels of modeling sophistication. A brief overview of the case studies is provided in this section of *ACRP Report 79*. The ACRP Project 03-17 final report, including detailed descriptions of the case studies, has been posted to the ACRP Project 03-17 web page at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2579.

Each case study is categorized into one of the following categories:

- Airport master plans
- Airport system plans
- Airport capacity studies
- Airport environmental studies
- FAA airfield capacity studies
- Academic and research studies

Each case study was examined to determine which of the following series of characteristics were included in the analysis:

- **Applications:** Capacity benefits, aircraft delay, future technologies, environmental constraints, system planning

		Level 1	Level 2	Level 3	Level 4	Level 5
How much time/budget is there?						
	Hours/<$5k	■	■			
	Days/<$25k	■	■	■		
	Weeks/<$50k	■	■	■	■	
	Months/$100k+	■	■	■	■	■
What is the purpose of the capacity analysis?						
	To analyze a capacity change					
Airfield changes:	New runway	■	■	■	■	■
	New taxiway/apron/gates					■
	Runway crossings and incursions					■
	Navigational aid critical areas					■
	Effects of airport traffic control towers			■	■	■
Airspace changes:	Changes in flight procedures			■	■	■
	Noise abatement procedures				■	■
	In-trail terminal airspace restrictions					■
	Multiple approach procedures			■	■	■
	Changes in ATC rules and separations					■
	ATC workload and human factors			■	■	■
	NextGen benefits of reduced aircraft separations and new airspace procedures			■	■	■
Aircraft changes:	Aircraft fleet mix and stage length changes			■	■	■
	To estimate aircraft delay					■
	To estimate ASV/hourly capacity	■	■			
	To compare with hourly demand			■	■	■
	To benchmark with other airports	■	■	■	■	■
	To evaluate flight schedules			■	■	■
	To compare alternative airfield facility or procedural improvements			■	■	■
	To provide data for follow-on environmental studies			■	■	■
	To provide proof-of-concept testing	■	■	■	■	■
	To provide information to educate elected officials, the general public, or other stakeholders	■	■	■	■	■
What data are avaliable?						
Airfield data:	Runway use/assignments					■
	Runway layout	■	■	■	■	■
	Runway exit locations		■			■
	Runway dependencies					■
	AROT			■	■	■
	DROT			■	■	■
	Airfield layout in AutoCAD					■
Aircraft data:	Percent arrivals		■			■
	Mix index	■	■	■	■	■
	Flight schedule					■
	Fleet mix			■	■	■
	Final approach speeds			■	■	■
Airspace data:	Departure-departure separations			■	■	■
	Departure-departure separations					■
	Departure flight tracks					■
	Capture distance					■
	Arrival-departure separations			■	■	■
	Arrival-arrival separations			■	■	■
	Arrival-arrival separations					■
	Arrival flight tracks					■
What factors do you need to capture?						
	Geometry					
	Effect of runway exit taxiway location		■	■	■	■
	Supporting taxiways					
	Departure queue sequencing					■
	Runway crossings					■
	Parallel taxiway					■
	Aircraft performance					
	Effect of runway occupancy time			■	■	■
	Runway use					
	Runway-specific fleet mix (due to noise or length)				■	■
	Multiple approach technology				■	■
	Airspace					
	Departure fix restrictions				■	■
	Limited departure headings				■	■
What degree of public scrutiny or challenge will the results of your study receive from airport staff and airport stakeholders?	**Public scrutiny**					
	Little or no scrutiny or challenge	■	■	■	■	■
	Low level of scrutiny or challenge		■	■	■	■
	Moderate level of scrutiny or challenge			■	■	■
	Intense level of scrutiny or challenge				■	■

Figure 5-2. High-level matrix for choosing a level of modeling sophistication.

LEVEL 1 - Lookup Tables in AC 150/5060-5 or New Level 1 Spreadsheets

1. Do the lookup tables reflect your situation or can they be changed to reflect it? (parallel taxiway, ILS runway, ATCT, etc.)
2. Do the lookup tables include your specific runway uses, or can they be changed to include them?

*If you answered **YES** to both these questions, **use a Level 1 model.***
*If you answered **NO** to either of these questions, **go to Level 2 questions.***

LEVEL 2 - AC 150/5060-5 Charts/Nomographs or New Level 2 Spreadsheets

1. Do you have three or more runways?
2. Will the results be subject to a high level of scrutiny, challenge, or controversy?
3. **AC only**–Do you need to represent the fleet mix in more detail than the "mix index"?
4. **AC only**–Do you need to consider detailed runway occupancy time data?
5. **AC only**–Do you need to reflect a change from the standard default aircraft separations?
6. **AC only**–Do you have arrival/departure separations not included in the charts?
7. **AC only**–Do you have runway crossings that interrupt your arrival/departure flow?
8. **AC only**–Are you assessing operations during weather conditions other than VMC or IMC?

*If you answered **NO** to all of these questions, **use a Level 2 model.***
*If you answered **YES** to any of these questions, **go to Level 3 questions.***

LEVEL 3 - Analytical Models or New Level 3 Spreadsheets

1. Is the use of the runway(s) restricted to certain aircraft types (e.g., because of noise abatement measures or runway length)?
2. Does the availability of departure fixes/headings restrict operations?
3. Does arrival track geometry affect aircraft separations?
4. Do you have a dependent or converging arrival runway operation?

*If you answered **NO** to all of these questions, **use a Level 3 model.***
*If you answered **YES** to any of these questions, **go to Level 4 questions.***

LEVEL 4 - Airfield Capacity Simulation Models (e.g., *runway*Simulator)

1. Do you need to consider a detailed matched flight schedule?
2. Do you need to model the full airport system, including gates, apron, and taxilanes?
3. Are you considering taxiways other than runway exit taxiways or single parallel taxiways?
4. Do you have airspace conflicts with neighboring airports, restricted airspace, etc.?
5. Do you need to explicitly model the terminal airspace?
6. Will you need to demonstrate or validate the baseline results to stakeholders using computer animation graphics to convince them that the results are valid and credible?

*If you answered **NO** to all of these questions, **use a Level 4 model.***
*If you answered **YES** to any of these questions, **use a Level 5 model.***

Figure 5-3. Decision hierarchy for selecting level of modeling sophistication.

Table 5-1. Explanatory comments on questions in decision hierarchy.

LEVEL 1 - Lookup Tables in AC 150/5060-5 or New Level 1 Spreadsheets	
1. Do the lookup tables reflect your situation or can they be changed to reflect it? (parallel taxiway, ILS runway, ATCT, etc.)	Level 1 spreadsheets provide more flexibility for handling deviations from default assumption
2. Do the lookup tables include your specific runway uses, or can they be changed to include them?	Level 1 spreadsheets provide more flexibility for changing runway uses
	*If you answered **YES** to both of these questions, **use a Level 1 model.*** *If you answered **NO** to either of these questions, **go to Level 2 questions.***

LEVEL 2 - AC 150/5060-5 Charts/Nomographs or New Level 2 Spreadsheets	
1. Do you have three or more runways?	Three or more runways constitute a complex airfield, which necessitates a minimum level of analysis. Current Level 2 spreadsheets handle up to two runways only.
2. Will the results be subject to a high level of scrutiny, challenge, or controversy?	If the project or capacity change being analyzed has a high profile among the public and is likely to be highly scrutinized or attract media attention, a minimum level of analysis is necessary to ensure credible results.
3. **AC only**–Do you need to represent the fleet mix in more detail than the "mix index"?	This question applies to the AC only; new spreadsheets allow the user to specify detailed aircraft fleet mixes. If a mix-index representation of the aircraft fleet mix is not sufficient, then the AC Level 2 charts and nomographs cannot be used.
4. **AC only**–Do you need to consider detailed runway occupancy time data?	This question applies to the AC only; new spreadsheets allow the user to specify detailed runway occupancy times. If detailed analysis of runway occupancy times by aircraft type is available for the specific runway exit geometry, these data should be reflected in the capacity analysis.
5. **AC only**–Do you need to reflect a change from the standard default aircraft separations?	This question applies to the AC only; new spreadsheets allow the user to specify detailed aircraft separations. If actual aircraft separations at the airport do not reflect the minimum standard separations typically encountered, custom adjustments must be made to these assumptions.
6. **AC only**–Do you have arrival/departure separations not included in the charts or spreadsheets?	This question applies to the AC only; new spreadsheets allow the user to specify arrival-departure separations. If runways are operated in a mixed mode or dependent segregated manner (i.e., arrivals on one, and departures on the other), a departure cannot be released unless the arrival is a certain distance away from the runway threshold, which must be changeable if the default assumptions do not apply.
7. **AC only**–Do you have runway crossings that interrupt your arrival/departure flow?	This question applies to the AC only; new spreadsheets allow the user to specify detailed runway crossing effects. Runway crossings decrease the amount of time that the runway is able to be used for arrivals or departures, therefore decreasing runway capacity.
8. **AC only**–Are you assessing operations during weather conditions other than VMC or IMC?	This question applies to the AC only; new spreadsheets allow the user to specify detailed weather characteristics. Typically, VMC and IMC conditions are the most critical. However, in some situations, other weather conditions may be of interest, particularly when an airport experiences changes in runway use or procedures under other defined weather minima (marginal VMC, Category II/III Instrument Landing System operations, etc.).
	*If you answered **NO** to all of these questions, **use a Level 2 model.*** *If you answered **YES** to any of these questions, **go to Level 3 questions.***

Table 5-1. (Continued).

LEVEL 3 - Analytical Models or New Level 3 Spreadsheets	
1. Is the use of the runway(s) restricted to certain aircraft types (e.g., because of noise abatement measures or runway length)?	If a runway is only available for use by certain types of aircraft, this runway use needs to be reflected in the capacity analysis. Runways with use restrictions will only be able to contribute to capacity as much as aircraft in the mix are eligible to use the runway.
2. Does the availability of departure fixes/headings restrict operations?	If consecutive departures follow the same route and, therefore, must be spaced farther apart than the minimum requirement possible with divergent departure headings, a departure fix or heading restriction exists.
3. Does arrival track geometry affect aircraft separations?	Arrival track geometry could affect the ability to conduct certain individual or simultaneous instrument approach procedures.
4. Do you have a dependent or converging arrival runway operation?	If an airport has two dependent, intersecting, or converging arrival runways that are operated simultaneously, the applicable multiple instrument approach procedure must be considered when estimating capacity.
	*If you answered **NO** to all of these questions, **use a Level 3 model.*** *If you answered **YES** to any of these questions, **go to Level 4 questions.***

LEVEL 4 - Airfield Capacity Simulation Models (e.g., *runway*Simulator)	
1. Do you need to consider a detailed matched flight schedule?	If the goal of the capacity analysis is to assess changes in airline flight schedules or demand for gates throughout a day, a matched flight schedule is the ideal way to analyze such capacity issues. Only the Level 5 model sophistication currently allows a detailed flight schedule to be used as input.
2. Do you need to model the full airfield system, including gates, apron, and taxilanes?	Analyzing the airfield components as a complete system requires a modeling tool that can consider the full airfield system. When airfield infrastructure other than runways and taxiways that interact with runways must be reflected in a capacity analysis, a Level 5 model should be selected.
3. Are you considering taxiways other than runway exit taxiways or single parallel taxiways?	Typically, taxiways, other than runway entrance/exit taxiways or parallel taxiways, do not affect runway throughput or, therefore, capacity. However, in some situations, unique taxiway issues or resolving taxiway bottlenecks may be the focus of an analysis, which requires a Level 5 simulation.
4. Do you have airspace conflicts with neighboring airports, restricted airspace, etc.?	If operations at neighboring airports or restricted airspace in the airport vicinity restrict the runway system from being used to the fullest extent possible, airspace conflicts need to be reflected in the capacity analysis. A Level 5 simulation is required in this case.
5. Do you need to explicitly model the terminal airspace?	If the close-in airspace structure affects the efficiency of departure and arrival runway operations, these effects should be accounted for in a capacity estimate. Level 5 models can reflect aircraft flight paths in and out of the terminal airspace; other level models cannot.
6. Will there be a need to demonstrate or validate the baseline results to stakeholders using computer animation graphics to convince them that the results are valid and credible?	Capacity projects subject to intense scrutiny are more easily understood by a non-technical audience through the use of visuals. Computer animation graphics also can be helpful in reviewing the assumptions with air traffic specialists and gaining acceptance of the results.
	*If you answered **NO** to all of these questions, **use a Level 4 model.*** *If you answered **YES** to any of these questions, **use a Level 5 model.***

Source: ACRP 03-17 Research Team.

Table 5-2. Summary of airport capacity case studies: Conditions and levels of modeling sophistication used—ACRP Project 03-17, "Evaluating Airfield Capacity."

		Main Purposes of Airfield Capacity Analysis					Elements of Airfield Considered					Airfield Capacity Metrics		Level of Modeling Sophistication		
	Case Study (short title)	Capacity Benefits	Aircraft Delay	NextGen Technologies	Environmental Constraints	System Planning	Runways	Taxiways	Gates	Terminal Airspace	NAS	Hourly Throughput	Annual Service Volume	Level 1 & 2 AC	Level 3 Analytical	Level 5 Simulation
	Master Plans															
1	Airport Master Plan (ARW)		X				X					X	X	X	X	
2	Airport Master Plan (CHD)		X				X					X	X	X	X	
3	Master Plan Update (MEM)		X				X	X		X		X				X
4	Master Plan (BWI)	X	X				X	X	X			X				X
	System Plans															
5	Airport System Plan Update (New Mexico)					X	X	X							X	
6	Regional Airport System Demand Study (NY/NJ)					X	X	X	X			X		X	X	
	Capacity Studies															
7	Update of Airfield Analysis (HOU)	X	X				X					X	X		X	
8	Airport Expansion Feasibility Study (PBC)	X					X	X				X	X		X	
9	Ultimate Airfield Capacity Study (OAK)		X	X	X		X									X
10	Analysis of Airside and Gate Capacity (SFO)		X				X		X			X			X	
11	Airside Capacity Study (JFK)	X		X			X	X	X			X			X	
12	Delay Reduction Study (JFK)	X	X				X	X		X		X			X	
	Environmental Studies															
13	Part 161 Study (BUR)				X	X	X			X		X		X	X	
14	Environmental Impact Statement (FLL)	X	X		X		X	X	X			X				X
15	Part 150 Study (CVG)	X			X		X					X			X	
	FAA Airfield Capacity Studies															
16	AC-150/5060-5 Airport Capacity and Delay	X	X				X	X	X			X	X	X	X	
17	Capacity Enhancement Plan (CEP) for MEM	X														
18	Airport Capacity Benchmark Report	X		X			X					X			X	
19	Capacity Needs in the National Airspace System	X	X	X		X	X				X	X	X		X	
	Academic and Research Studies															
20	Low Visibility Landing and Surface Operations Runway Occupancy Time	X					X								X	
21	Optimal Level of Operations on an Arrivals Only Runway						X								X	
22	Computer Simulation Model for Airplane Landing Performance	X					X									X
23	Improvements in Simple Models for Estimating Runway Capacity	X					X								X	
24	Validation of Runway Capacity Models						X					X			X	
25	Delay Impacts of an Airport Enhancement (Detroit)	X		X			X								X	
26	Scenario-Based Management of Air Traffic Flow		X			X	X			X	X				X	X
27	North Airfield Safety Study (Los Angeles)	X	X				X	X				X				X

Source: ACRP 03-17 Research Team.

- **Elements of Airfield Considered:** Runways, taxiways, gates, terminal airspace, NAS
- **Airfield Capacity Metrics:** Hourly throughput, annual service volume
- **Level of Modeling Sophistication:** Level 1 and 2 table lookup or nomographs (e.g., the AC); Level 3 analytical models (e.g., the ACM); and Level 5 aircraft delay simulation (e.g., SIMMOD and TAAM)

Table 5-2 summarizes key features of the case studies. The levels of modeling sophistication used in each study are shown in the three right-hand columns of the table.

Notice that in Table 5-2 the most frequently used level of modeling sophistication is Level 3, analytical models. The table also shows that several of the studies involved the use of more than one level of modeling sophistication. Four of the airport planning studies used Level 5 aircraft delay simulation, as did three of the academic and research studies. The smaller airport master planning studies used Level 1, Level 2, and Level 3 capacity models, while the larger airport master planning studies used Level 5 simulation, as one would expect.

CHAPTER 6

Subsequent Uses of Airfield Capacity Estimates

Airfield capacity alone is a very useful performance metric, but its real value can only be realized by comparing it with existing and future demand for aircraft operations in subsequent applications. Many and diverse applications of airfield capacity information are available in the aviation industry. This chapter briefly describes a few of the most common applications of airfield capacity information in aviation planning and decision making, as follows:

- Making demand-capacity comparisons
- Providing data for environmental analyses
- Informing benefit-cost analysis (BCA)
- Balancing airfield capacities with passenger terminal and landside facility capacities
- Demand/congestion management (FAA)
- Benchmarking with other airports
- Measuring the progress of the Next Generation Air Transportation System (NextGen)
- Input to models for estimating aircraft delays
- Application of airfield service volumes and aircraft delay thresholds
- Defining and measuring aircraft delay and airport capacity thresholds

Making Demand-Capacity Comparisons

Airfield capacity estimates are commonly used to assess whether (1) existing airfield capacity will be sufficient to meet existing or forecast demand, and (2) proposed capacity enhancements will enable the airfield to meet forecast demand. Such demand-capacity assessments typically are made as part of airport master planning and system planning studies, which are typically followed by environmental reviews and assessments of the recommended capacity enhancements.

Comparing a capacity estimate with demand can indicate the potential performance of an airfield and the need for additional capacity. The ultimate capacity of an airport is largely determined by the capacity of its airfield. Capacities of other airport components (taxiways, gates, the terminal, and access roadways) are rarely the limiting factors of an airport system. Balancing airfield capacity with the capacities of other airport components is discussed later in this chapter.

Airfield capacity can be compared with demand on an hourly and an annual basis, as discussed below.

Hourly Airfield Demand-Capacity Comparisons

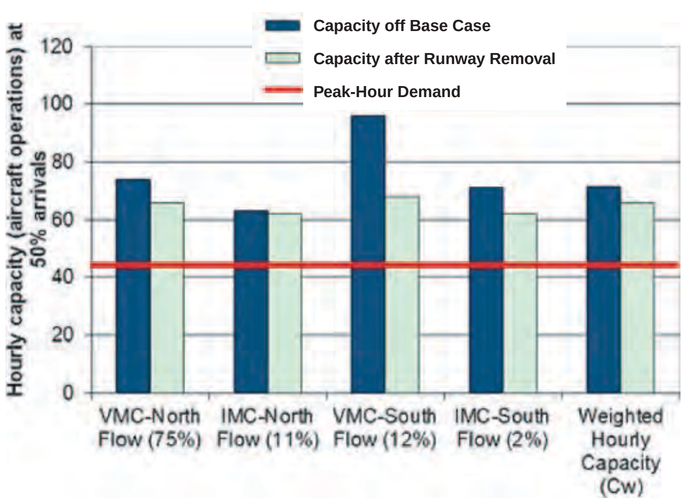
Evaluating hourly demand versus hourly capacity is the first step in a demand-capacity comparison. In the United States, the typical demand level selected for such hourly demand-capacity comparisons is the peak hour of the average day, peak month (ADPM). Making comparisons with the ADPM peak hour should ensure that sufficient capacity is provided for most days of the year, recognizing that there may be periods during very busy days when delays, congestion, and queuing will occur.

In some situations, selection of the ADPM peak hour is not appropriate for measuring demand and could result in an underestimation of demand at peak times. In these cases, it may be appropriate to use a design-hour volume based on a specific percentile (e.g., 90th or 95th percentile) of the busiest hours of the year. The concept of design-hour volume for aircraft traffic is similar to that of design-hour volume as used for other modes of transportation. For example, in highway design, the demand during the 30th busiest hour of the year is typically used as the design-hour volume.

Hourly throughput capacity can be estimated using any of the capacity analysis methods discussed in this guidebook. If peak-hour demand typically consists mostly of arrivals or mostly of departures, it may be appropriate to compare that demand to the airfield capacity for the corresponding percentage of arrivals (e.g., if peak-hour demand tends strongly toward more departures, then a 30% arrival capacity would be appropriate for comparison; if peak-hour demand tends strongly toward more arrivals, then a 70% arrivals capacity would be appropriate for comparison).

The maximum sustainable throughput capacity typically is close to or higher than the highest observed actual flow rates on the airfield, but it can be exceeded during certain busy hours of the year. Estimates of maximum sustainable throughput capacity are based on assumptions regarding average aircraft approach speeds, minimum separation requirements (computed as the minimum required separations plus a buffer), average runway occupancy times, and either average or peak-hour aircraft fleet mix. During certain hours of the year, conditions may differ from these assumed average values, which can result in actual observed throughput rates that are greater than or less than the estimated maximum sustainable throughput capacity.

Many applications for airfield capacity estimates require a simple comparison of hourly airfield capacities with existing or forecast peak-hour operations. Again, any level of modeling sophistication could produce estimates of hourly runway capacity for purposes of comparison with estimates of peak-hour demand. If this is the only application of such airfield capacity estimates, however, then the less sophisticated models typically are adequate. Figure 6-1 shows an example of an hourly demand-capacity comparison.



Source: LeighFisher.

Figure 6-1. Example of a comparison of peak-hour demand with hourly airfield capacity.

Annual Airfield Demand-Capacity Comparisons

For the majority of airports, comparing an estimate of annual airfield capacity with estimates of annual demand for aircraft operations is sufficient to determine the need for airfield improvements.

The annual capacity of an airfield does not equal hourly capacity multiplied by 24 hours in the day and 365 days in the year. Capacity provided during hours when there is little or no demand is not relevant. Estimates of annual capacity must account for variations in demand over the hours of the day and months of the year. Consequently, ASV was developed as an estimate of an airport's annual capacity to accommodate aircraft operations considering the variations in demand. ASV is not a hard ceiling number; rather, it is intended to be interpreted as the number of actual annual aircraft operations *above which* additional increases in aircraft operations would result in disproportionate increases in average aircraft delays.

In calculating ASV, a weighted average of the hourly capacities over the year, computed using formulas specified in FAA's AC 150/5060-5, *Airport Capacity and Delay* (the AC), is expanded to an annual number by multiplying by the ratio of ADPM operations to peak-hour operations, and the ratio of annual operations to ADPM operations. Thus, ASV is calculated using the following formula:

$$ASV = C_w \times D \times H$$

where

C_w = the weighted average hourly capacity of the airfield,
D = the ratio of annual to ADPM demand, and
H = the ratio of ADPM demand to peak-hour demand.

Any level of modeling sophistication could be used to estimate hourly runway capacities under different runway uses and weather conditions, to estimate a weighted hourly capacity, and, subsequently, to estimate ASV. Such hourly capacities typically are referred to as *balanced hourly airfield capacities* or *equivalent 50% arrivals hourly airfield capacities.*

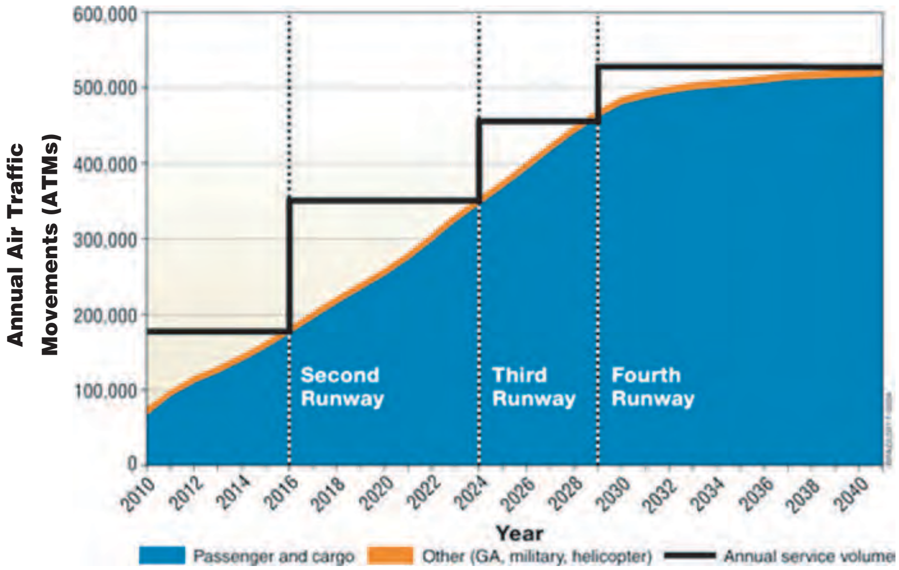
The ratios for D and H should be calculated using data from airport records or publicly available sources on air traffic demand pattern. When demand data are not available, the recommended default values in the AC can be used.

The D factor measures seasonal variation in monthly demand, where a value of 365 would indicate that all months have the same demand. Very low D values (e.g., values less than 300) would indicate substantial seasonality typical of vacation destinations.

The H factor measures variation over the hours of the day, where a value of 24 would indicate that all hours of the day have the same demand. Much lower H values (e.g., values less than 12) would indicate substantial peaking in demand over the hours of the day.

Annual capacity estimates can inform the number of operations at which new airfield infrastructure would be needed to accommodate demand. Figure 6-2 shows an example of comparing forecast annual demand to estimated ASV for different airfield development scenarios. Ideally, airfield capacity would be increased incrementally through new infrastructure or procedures to accommodate forecast demand.

Demand-capacity comparisons such as those described above are most often made as part of a master plan or system plan to determine whether further analysis is needed. Identified capacity shortfalls, driven by growing demand, will require additional runways or taxiways, or improved air traffic control procedures. The capacity analysis forms the basis for developing and evaluating alternatives, and for selecting the preferred alternative to best accommodate future demand. At small airports, airfield capacity typically exceeds expected demand by a wide margin; therefore,



Source: LeighFisher.

Figure 6-2. Example of an annual demand-capacity comparison.

reporting the estimated airfield capacity in a master plan or system plan will most often satisfy any requirements for airfield capacity analysis and facility requirements.

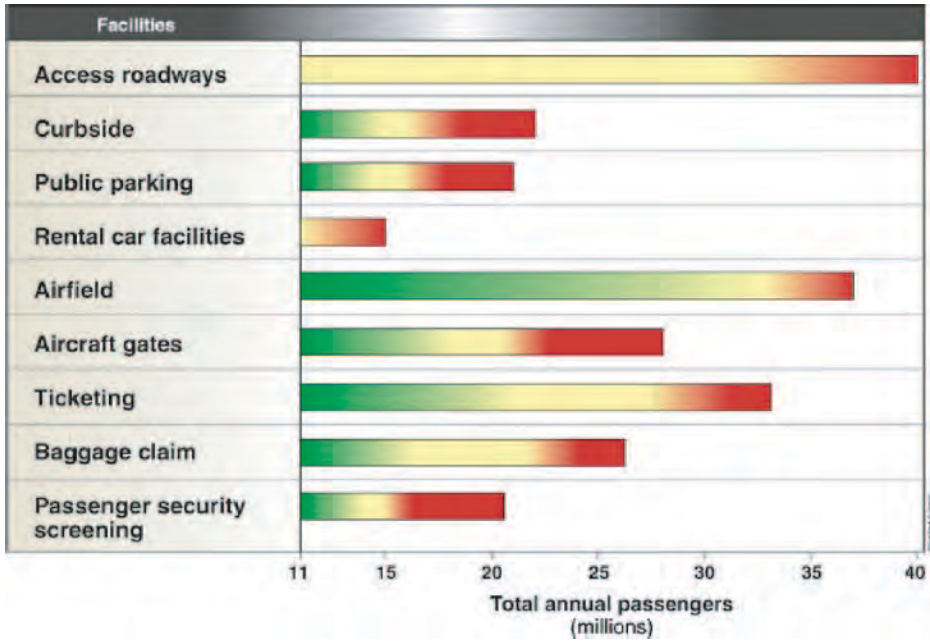
For airport master planning and system planning, capacity estimates are typically required for a wide variety of facility and procedural alternatives. For preliminary screening of alternatives, analytical models or spreadsheets are usually the preferred methods for evaluating airfield capacity. Once the alternatives have been screened down to a manageable number for detailed analysis, airfield simulation analysis may then be justified to distinguish among the final alternatives.

Providing Data for Environmental Analyses

Airfield capacity estimates are important inputs to certain environmental analyses, such as (1) air quality analyses, where changes in queuing locations or times could result in a change in the location and level of emissions; and (2) aircraft noise analyses, where changes in runway use or fleet mix on a runway could change noise exposure patterns. In some cases, less sophisticated models are adequate to evaluate capacity differences between alternative airport improvements, but a more sophisticated model may be needed to provide the information needed for the environmental evaluation models used in the National Environmental Policy Act (NEPA) analysis process. Demand-capacity comparisons made for environmental analyses use average annual day (AAD) instead of ADPM because AAD is the demand metric used for aircraft noise exposure analyses.

Informing Benefit-Cost Analysis

A BCA is required for airport capacity projects that exceed $10 million in discretionary grants from FAA. Capacity projects studied in BCAs include new or extended runways, taxiways, aprons, or hold pads. The monetization of benefits typically revolves around translating the expected capacity increase into a quantifiable benefit, whether the project is expected to reduce passenger or aircraft delays, improve schedule predictability, or enable larger aircraft.



Source: LeighFisher.

Figure 6-3. Stoplight chart comparing annual capacities of various airport components.

Balancing Airfield Capacities with Passenger Terminal and Landside Facility Capacities

At most airports, the capacity of the airfield system determines the ultimate capacity of the airport. However, prudent planning requires that airfield capacity be balanced with the capacities of other airport components, such as the terminal complex, ground access roadways, and the cargo complex. This balancing is usually accomplished in the facility requirements portion of an airport master plan. Figure 6-3 shows a sample chart comparing annual capacity in terms of total annual passengers using the various airport components. In this case, the access roadways and airfield have the highest annual capacities, whereas the rental car facilities and passenger security screening facilities have the lowest annual capacities. This type of chart is sometimes referred to as a stoplight chart because the colors green, yellow, and red are used to indicate the degree of demand saturation or congestion.

Demand/Congestion Management (FAA)

Fan and Odoni define demand-management measures as any set of administrative or economic measures, or combinations thereof, aimed at balancing aircraft operations demand with airport capacities.[1] These measures typically are intended to limit the number of peak-hour flights through slots or auctions so that aircraft delays do not become excessive. The term *congestion management* has been widely used recently, sometimes in conjunction with demand management, which sometimes is expressed as congestion management by demand-management measures.

[1]T. P. Fan and A. R. Odoni, "A Practical Perspective on Airport Demand Management," *Air Traffic Control Quarterly,* Vol. 10, No. 3, pp. 285–306, 2002.

Such demand-management measures in the United States were initiated in 1968 when FAA issued the High Density Traffic Airports Rule (HDR) (14 CFR Part 93 Subpart K), to reduce delays at five congested airports—John F. Kennedy International, LaGuardia, Newark Liberty International, Chicago O'Hare International, and Ronald Reagan Washington National airports—and such measures have continued to be proposed in one form or another in various legislative and administrative rulemakings to the present day. Nearly all of these demand-management initiatives have used estimates of airfield capacity as the basis for limiting operations at very congested airports.

Various airfield capacity metrics have been used over the years for setting limits on the number of slots allowed in demand-management initiatives at congested airports. These metrics have generally involved estimates of average hourly airfield capacity that are intended to control the level of aircraft delays expected to occur at a congested airport. Airfield capacity limits also have been expressed in terms of maximum permitted operations in 15-minute intervals, and certain limits have been expressed in terms of the maximum numbers of flights permitted by certain classes of aircraft or air service. Up to now, however, no metric has been universally accepted for use in demand-management measures, and the recommended metrics have been typically site-specific and restricted by U.S. law.

Benchmarking with Other Airports

FAA's *Airport Capacity Benchmark Report 2001* and *Airport Capacity Benchmark Report 2004* were prepared by MITRE Corporation using the FAA Airfield Capacity Model (ACM) along with interviews and data on airport arrival rates (AARs) and airport departure rates (ADRs) provided by local air traffic specialists. In 2011 and 2012 MITRE updated the *Airport Capacity Benchmark Report* using its *runway*Simulator model, which is described in Chapter 4. As this guidebook was being prepared for publication, the 2012 benchmark capacities were anticipated but had not yet been released to the public.

Airport operators also have recently prepared a variety of benchmarking studies. Among the factors considered in these benchmarking studies are airfield capacity and aircraft delay. For this purpose, airport operators need a metric that is readily available for their own airport and for comparable airports. For purposes of comparing airfield capacities, FAA's *Airport Capacity Benchmark Reports* are a good source of capacity estimates for airport operators.

Measuring the Progress of NextGen

FAA is developing a set of NextGen performance assessment metrics based on the International Civil Aviation Organization (ICAO) key performance areas (KPAs). ICAO has defined a capacity KPA as a measure of the ability of the national airspace system, an airspace sector, a metroplex, or an airport to accommodate demand.

The capacity KPA has been defined in terms of both the actual throughput in peak demand periods and the maximum throughput capability in a specified time interval. The main difference between these two definitions is that actual throughput can be measured by direct observation, while maximum throughput capability must typically be calculated using available data and models that reflect the rules and procedures that determine capacity. Actual throughput can be used to estimate and validate maximum throughput capability, and also to determine the degree to which the maximum throughput capability is being used.

For the maximum throughput capability metric applied to airports, FAA expects to use its AARs and ADRs, the maximum number of landings and takeoffs that can be accommodated at an airport under a given set of operating conditions. The FAA *Pilot/Controller Glossary* defines these rates as follows:

> **Airport Arrival Rate (AAR):** A dynamic input parameter specifying the number of arriving aircraft that an airport or airspace can accept from the Air Route Traffic Control Center per hour. The AAR is used to calculate the desired interval between successive arrival aircraft.
> **Airport Departure Rate (ADR):** A dynamic parameter specifying the number of aircraft that can depart from an airport and that the airspace can accept per hour.[2]

AARs and ADRs are calculated using a combination of controller judgment, analyses of actual throughput data, and airfield capacity modeling. As NextGen procedural and operational improvements are introduced, these AARs and ADRs will be recalculated to reflect the improved capabilities. FAA expects to use these updated AARs and ADRs as high level metrics for the post-implementation measurement of the effects of NextGen improvements on airfield capacity.

AARs and ADRs are provided by the Air Traffic Control System Command on a daily basis for a set of 77 airports tracked by FAA's Aviation System Performance Metrics (ASPM) database. The AARs and ADRs are based on time of day, flight schedules (from OAG), available staff to handle traffic, weather conditions (ceiling and visibility), and runway configurations.

Input to Models for Estimating Aircraft Delays

Airfield capacity estimates often are input into models used to estimate aircraft delays. Usually, hourly runway capacity estimates appropriate for this purpose would be obtained using Level 3 or Level 4 airfield capacity models. Average aircraft delays can then be estimated using an analytical model that compares hourly demand with hourly capacity, typically over a 1-year period. The calculation of delay within such an analytical model usually is based on queuing theory models or equivalent cumulative demand versus capacity comparisons.

One such model is the FAA Annual Delay Model. In addition, various airport consultants and researchers have developed their own analytical delay models for estimating average aircraft delay using estimates of hourly demand and hourly airfield capacity as the key inputs. Level 5 delay simulation models provide estimates of aircraft delay as their primary output.

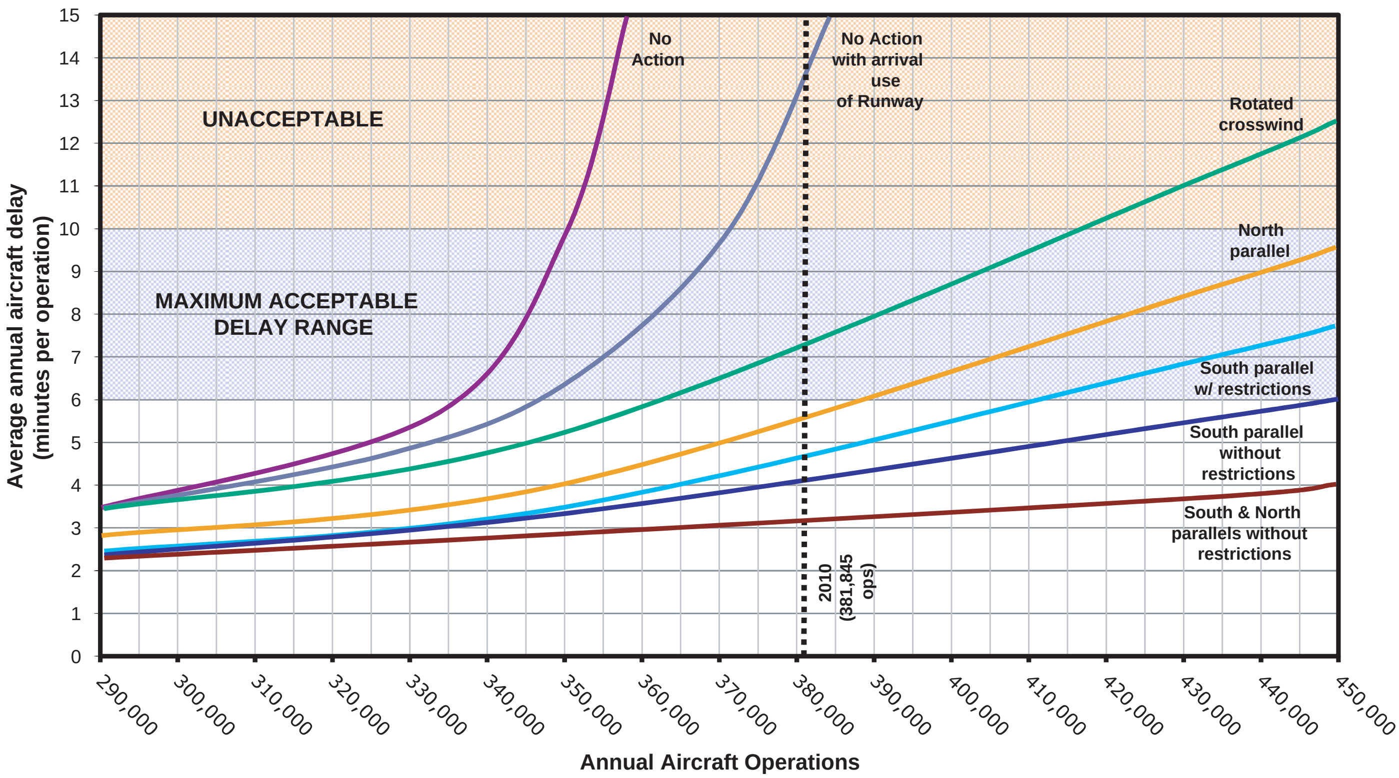
Aircraft delays also can be estimated using the AC by comparing annual demand in terms of aircraft operations to estimated ASV calculated using the formula discussed in this chapter. Average aircraft delay can then be estimated by using the ratio of annual demand to ASV along with a set of delay curves presented in the AC, wherein the horizontal axis of those delay curves is the ratio of annual demand to ASV, and the vertical axis is average annual aircraft delay in minutes per operation.

Application of Airfield Service Volumes and Aircraft Delay Thresholds

As described under the definitions of capacity provided in Chapter 1 of this guidebook, there has long been interest in specifying a definition of practical airfield capacity or airfield service volume, which can be generally defined as follows:

> **Practical Airfield Capacity/Service Volume:** The maximum number of aircraft operations that can be accommodated on an airfield at a specified level of service,

[2]FAA's *Pilot/Controller Glossary* is an online document available at: http://www.faa.gov/air_traffic/publications/atpubs/pcg/A.HTM. (Accessed August 22, 2012).



Source: LeighFisher.

Figure 6-4. Typical aircraft delay curves for a set of airfield improvement alternatives showing ranges of acceptable versus unacceptable delays.

typically defined in terms of a threshold (or acceptable) level of average annual aircraft delay (e.g., 7 minutes per aircraft operation).

According to FAA guidance, "traditionally, 4 to 6 minutes of average annual delay per aircraft operation is used in ASV calculation. This can be considered as an acceptable level of delay. When the average annual delay per aircraft operation reaches 4 to 6 minutes, the airport is approaching its practical capacity and is generally considered congested."[3]

In a 1995 report to Congress, the U.S. Department of Transportation (DOT) states: "There are no defined criteria that delineate acceptable versus unacceptable delays."[4] Figure 6-4 illustrates the relationship between annual demand and average aircraft delay and the concept of expressing service volumes as a function of threshold levels of delay (i.e., acceptable and unacceptable levels of average aircraft delay).

In the absence of specific acceptability criteria for delays, the following scale for levels of service was suggested in the 1995 report to gauge the extent to which delays are tolerated rather than accepted:

- **4 to 6 Minutes of Delay per Operation.** Less efficient overall operations; limited peak-hour visual flight rules (VFR) delays along with instrument flight rules (IFR) delays experienced in both moderate and extreme weather conditions.

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[3]FAA. AC 150/5070-6B, *Airport Master Plans,* May 2007.

[4]GRA, Inc. *A Study of the High Density Rule, Technical Supplement Number Three, Analytical Concepts and Methods,* prepared for the U.S. Department of Transportation, Federal Aviation Administration, May 1995.

- **6 to 8 Minutes of Delay per Operation.** Increasing VFR delays in peak hours; increasing delays and eroding operational reliability in IFR conditions; high sensitivity to operational anomalies.
- **8 to 10 Minutes of Delay per Operation.** Increasing VFR delays in peak hours with translation to shoulder hours in all but optimum conditions; high delay in IFR conditions with resulting flight cancellations.
- **Over 10 Minutes of Delay per Operation.** VFR operations experience increasing delays in peak periods and shoulder hours in all but optimum conditions; very high delays in IFR conditions, resulting in extensive flight cancellations.

Defining and Measuring Aircraft Delay and Airport Capacity Thresholds

A detailed description of how aircraft delay is measured and identification of the thresholds of aircraft delay that would warrant capacity enhancements are outside the purview of this guidebook. However, ACRP Project 03-20, "Defining and Measuring Aircraft Delay and Airport Capacity Thresholds," is a natural follow-on to *ACRP Report 79* and will address these delay topics. The research findings developed under ACRP Project 03-20 are expected to (1) provide an inventory of and describe the different aircraft delay and airfield capacity metrics used within the industry, and (2) offer guidance about various delay and capacity metrics and when they should be used, particularly within the context of evaluating capacity enhancements. Research results of ACRP Project 03-20 are expected to be completed in 2012.

Appendix A

Prototype
Airfield Capacity
Spreadsheet Model

User's Guide

INTRODUCTION

The Prototype Airfield Capacity Spreadsheet Model (Airfield Capacity Spreadsheet Model) was developed for ACRP Project 03-17, "Evaluating Airfield Capacity," and is intended to serve as a prototype modeling tool to help airport planners understand and determine airfield capacity. Airfield capacity is the estimated number of total operations that a given airfield configuration can facilitate in a given period of time and under a given set of assumptions regarding fleet mix, separation minima rules, weather conditions and technological aides.

For many years the ability to quickly estimate an airfield's potential operational capacity has been limited to rules of thumb for simple configurations and a lookup table provided in the 1983 FAA Advisory Circular 150/5060-5, *Airport Capacity and Delay* (the AC). Varying levels of sophistication from spreadsheet models to full simulation modeling continue to advance and provide additional tools for planners to assess the existing and future airfield capacity under varying scenarios. The Airfield Capacity Spreadsheet Model can serve as an intermediary between the existing lookup tables available in the current AC (some of which are replicated utilizing new calculations on this spreadsheet model) and full simulation modeling.

The Airfield Capacity Spreadsheet Model is built on base calculations following the theory in the FAA Airfield Capacity Model (ACM) and applies variable separation, spacing and clearance standards following the guidelines included in FAA JO 7110.65, *Air Traffic Control,* and FAA EM-78-8A, *Parameters of Future ATC Systems Relating to Airport Capacity/Delay*. The FAA ACM referenced is discussed in detail in FAA RD-76-128, Reference 1.

The new spreadsheet model is designed to function as a working planning tool and is sensitive to most input changes that will dynamically represent real conditional changes on most simple to moderately complex airfield configurations.

This spreadsheet modeling tool is intended to serve as a beginning-level capacity calculation option. The model is not intended for complex airfield calculations or for use when a higher degree of specificity is required when supporting large-scale airfield redevelopment projects or highly controversial capacity projects. As outlined in the model selection criteria in Chapter 5 of the guidebook, large-scale and expensive capacity-related projects can support and should require the use of more detailed simulation efforts. The checklists provided in Chapter 5 will help to determine if sufficient data is available or can be assumed to provide enough of the necessary inputs to run the various models. In the absence of specific input parameters, the model can, in many cases, still be used, as many of the base default parameters can be used for simple single or dual runway airfields without significant unique restrictions. The Airfield Capacity Spreadsheet Model can be used to generate average or high level hourly capacity metrics depending on the data available and depth of knowledge.

Model worksheet areas have been formatted to print out on two sheets of legal paper for each of the three working models.

The Airfield Capacity Spreadsheet Model calculates average hourly capacity levels for the following general airfield configurations:

Single runway
Dual parallel runways
Dual intersecting runways

Each general configuration can be uniquely adjusted to closely fit the conditions of the user's specific airfield through selected input parameters.

The flowchart in Exhibit 1 provides a process overview of the steps involved in using the spreadsheet model with the necessary inputs to estimate airfield capacity.

Source: Landrum & Brown.

Exhibit 1. Prototype Airfield Capacity Spreadsheet Model flowchart.

Determination of airfield capacity is essentially based on the average time of separation between arriving aircraft and/or departing aircraft, which allows for a certain number of arrivals or departures to occur in an hour. The Airfield Capacity Spreadsheet Model attempts to model the interactions of different aircraft classes in a given fleet mix that follow all of the inputs regarding minimum spacing and air traffic rules. When sufficient spacing occurs between successive arrivals or departures, often one or more departures or arrivals can be released between the pairs, allowing for true mixed operations on the airfield. The optimal capacity is typically a balanced mix of arrivals and departures or a 50:50 mix.

DISCLAIMER

Significant research has been undertaken to prepare these analysis models for ACRP and much precaution has been taken to ensure that the models provide useful and applicable results to the area of airfield capacity planning. Neither ACRP, LeighFisher, nor Landrum and Brown Inc. assume any responsibility for errors or omissions of components in the development of this model, or for any damages resulting in the use of results from the spreadsheet model analysis. The developing group shall in no event be liable for any financial implications or loss of opportunity alleged to the use of resulting information assumed from use of this model.

SYSTEM REQUIREMENTS

The Airfield Capacity Spreadsheet Model runs in Excel and suitable for all versions of Microsoft Office Excel 2003 or newer. If the user's computer is currently successfully running Excel 2003 or newer, the spreadsheet model file should operate without any additional complication or issue.

The Airfield Capacity Spreadsheet Model does contain some simple macros for resetting many standard inputs and therefore require the macro function to be enabled. In Excel 2007 or Excel 2010, the "Enable Macros" button should appear in the ribbon at the top of the spreadsheet when the file is opened. Excel versions typically suggest not allowing all macros to run without authorization; therefore, most configurations are set to ask before running a macro or to disable any macros upon opening the file and prompt the user to change the security settings if necessary. To access the security settings in Excel 2007 and 2010, select the "File" tab or the "Windows Office" icon and navigate to "Options\Trust Center\Trust Center Settings" to change the security settings to enable the use of macros. In Excel 2003, navigate to the security settings by selecting the "Tools" menu and choosing "Macro\Security" to change the settings to "Medium." With the macros enabled, the functions in the Airfield Capacity Spreadsheet Model can perform as intended. If you encounter difficulty getting the "RESET INPUTS" button to work, more information is available on the "INTRO" tab on the spreadsheet.

The model's viewing area fits better on a wide screen monitor with a resolution of at least 1680 x 1050, but any monitor will suffice. Lower resolution monitors may not fully display the output section to the right without shifting the screen view more to the right.

OVERVIEW

The Airfield Capacity Spreadsheet Model consists of a macro-enabled Excel file (workbook) with several user tabs (spreadsheet tabs) that contain the operating configuration models, calculation worksheets, and supporting information on using the models and understanding the inputs and their individual effects on the output. The calculated output is the hourly airfield capacity determined by the combinations of the input data entered and model selections chosen as specific parameters for the airfield under consideration.

The workbook contains an introduction tab, labeled "INTRO," which contains some helpful definitions useful in navigating the model (see Exhibit 2). Note: A supplemental tab, labeled "Separation Layout" (not visible in the exhibit), provides a visual reference for understanding the determination of the arrival to arrival separation and interleaved departure time requirements described in the INTRO tab.

Exhibit 2. INTRO tab.

The INTRO tab also contains a legend, or "key" to the cell contents to help users identify the data associated with the fill and text colors used throughout the model (see Exhibit 3).

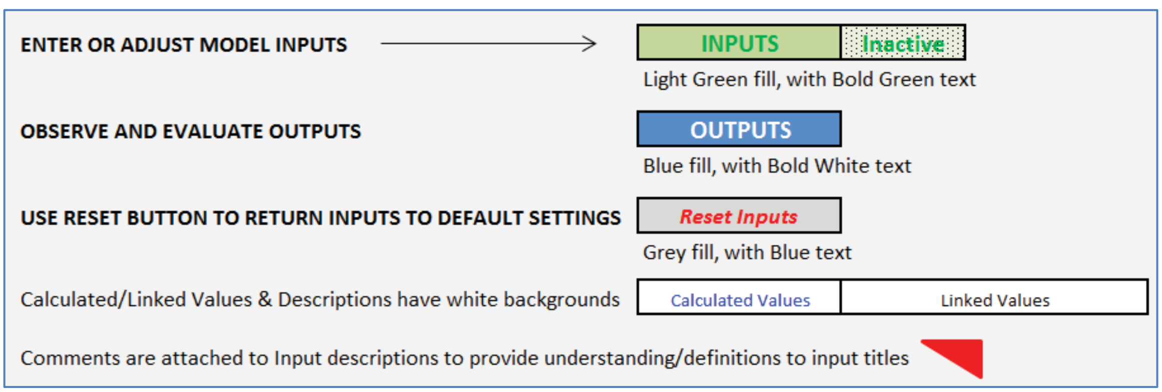


Exhibit 3. Cell contents key.

Next to the INTRO tab, a "Runway Layouts" tab has been included to graphically depict some of the terms and configurations illustrated within the models to help the user get a better understanding of the interaction involved in the models and the overall process involved in the calculations of the separation between aircraft (Exhibit 4).

Exhibit 4. Runway Layouts tab.

To protect the integrity of the Airfield Capacity Spreadsheet Model's information and formulas, *all of the worksheets have been protected;* however, the user can unprotect them as needed. There is no set password for the ancillary tabs, and for the model tabs the password is set as "**pass**". Caution: Do NOT change the password if you choose to unlock the models as the password is embedded in the macro codes.

The next tab in the workbook is labeled "Lookup Table" (Exhibit 5). This tab opens a sheet containing a lookup table in the format of the AC's Figure 2-1. This lookup table is just a sample of new lookup table results based on iterations performed using the default settings and assumptions that are in line with those expressed in the AC.

Exhibit 5. Lookup Table tab.

Of the original 19 configurations presented in the AC, five have been populated which best represent the usable outputs from the three configuration models included in the Airfield Capacity Spreadsheet Model tool. Exhibit 6 shows the results of the Single Runway Model.

General Runway-Use Configurations	New Aircraft Group Mix Percentages							Hourly Capacity Operations/Hour		Annual Service Volume
	A	B	C	C	C	C	D			
	S-S	S-T	S+	L-TP	L-J	L-757	H	VFR	IFR	Operations/Year
1.) Single Runway										
	100%	0%	0%	0%	0%	0%	0%	90	66	223,000
	25%	50%	25%	0%	0%	0%	0%	74	62	213,000
	5%	20%	20%	25%	25%	5%	0%	63	56	206,000
	0%	5%	10%	10%	65%	5%	5%	62	50	209,000
	0%	0%	5%	5%	55%	5%	30%	60	48	225,000

Exhibit 6. Portion of Lookup Table showing single runway configurations.

Three runway configuration tabs can be employed by the user to estimate hourly airfield capacity—"Single Model," "Dual Model," and "Intersecting Model" (Exhibit 7). Each tab opens a separate, but comparable, spreadsheet model as designed for a single runway, dual parallel runway, or intersecting runway configuration.

Exhibit 7. Single Model, Dual Model, and Intersecting Model tabs.

Selection of a model that reflects the user's airfield operating conditions is the first choice that must be made by the user. Default values are supplied in other sections of the model, but selection of the runway configuration is the first requirement in utilizing the Airfield Capacity Spreadsheet Model.

The next sections of the User's Guide provide explanations for use of the models reflecting the three airfield operating conditions provided in the Airfield Capacity

Spreadsheet Model, including details of the inputs that the user may enter or adjust to arrive at the hourly capacity output. It is assumed that the user will have limited knowledge of air traffic control rationale or FAA rules and guidelines on air traffic and pilot procedures regarding approach and departure routines. The explanations are intended to provide sufficient understanding to successfully use the capacity model, but not in such detail as to act as a tutorial on airfield capacity planning. The user is advised to become familiar with the spreadsheet tool as presented for the Single Runway Model (Single Model) before moving on to the Dual Parallel Runways Model (Dual Model) or the Dual Intersecting Runways Model (Intersecting Model), as the inputs and instructions for the latter two models build on information presented in the explanation of the Single Model.

SINGLE RUNWAY MODEL

The Single Runway Model (Single Model) is the simplest base configuration and will have the smallest number of variables, conditions and potential airfield conflicts. Having selected the Single Model, the user must then consider other inputs or choice selections.

Defaults (a standard set of inputs) are provided as a starting point for using each model. The Dual Model and Intersecting Model have additional configuration possibilities and will therefore have some additional input parameters to select or enter. There are basically two main areas for making inputs or choosing selections; General Inputs and Advanced Inputs. The general inputs allow the user to set up the conditions of the airfield and the fleet mix. These general inputs should be modified by the user, since the defaults that exist in the base model are unlikely to reflect the specific airfield and fleet mix conditions of the user's airport. While these general inputs are not requirements, they are essential to the production of a reasonable and relevant hourly airfield capacity. Beyond the general inputs are the advanced inputs, which allow for further refinement of data such as separation minima requirements that can also be modified. The advanced inputs, or advanced features, can be either shown in the spreadsheet model or left hidden by the user with the use of Excel radio buttons. The advanced features incorporate standardized separation minima requirements between pairs of arrivals and pairs of departures for both VMC and IMC weather conditions. It should be noted that if a user does not provide inputs in the advanced features section, the defaults reflect those included in FAA's EM-78-8A report on airport capacity and delay.

Cells within the runway configuration tabs are identified in a consistent manner to help the user quickly follow the flow of inputs, intermediate calculated values and outputs.

A "RESET INPUTS" button is available in each runway configuration model near the top of the INPUTS section (Exhibit 8).

Exhibit 8. RESET INPUTS button.

The user can change all of the input settings while customizing the conditions of a given airfield, and then return all of the standard (default) settings back to the original values by clicking the RESET INPUTS button.

The only settings that do not change back to default values when the RESET INPUTS button is clicked are the fleet mix share allocations, the VMC % occurrence under meteorological conditions, the operations assumption on touch-and-goes and the Runway Exit Availability and Full Parallel Taxiway selections.

General Inputs, Section 1

In the first section of general inputs the user makes selections regarding the specific operating conditions and air traffic control (ATC) practices for the airfield under consideration (Exhibit 9).

At a minimum in Section 1, the user must make an assumption regarding the percentage of total operations that consist of touch-and-go operations (see **Operations Assumption on Touch-N-Go's,** in Exhibit 9). This percentage is likely to be 0 if there isn't a flight training school or military airbase onsite. If the user has specific information on departure-arrival separation or the length of the common approach, the user **can** modify this information or rely on the defaults that are provided based on standard operating conditions as identified by FAA in ATC procedures.

INPUTS					
Meteorological Conditions	VMC, % Occurrence	90%	IMC, % Occurrence		10%
VMC-Departure-Arrival Separation	2.0	nm	Arrival - Arrival Std. Dev.	18.0	sec
IMC-Departure-Arrival Separation	2.0	nm	Departure ROT Std. Dev.	6.0	sec
Length of Common Approach	7.0	nm	Z-Value, 95% Confidence	1.645	------------
Operations Assumption on Touch -N- Go's		0%	T-Factor (Touch-N-Go's)	→	1.00

Exhibit 9. Single Model General Inputs Section 1.

Another key adjustment within Section 1 is the percentage of time the airfield operates under visual meteorological conditions (**VMC, % Occurrence**) and instrument meteorological conditions (**IMC, % Occurrence**). The basic criteria for determining VMC or IMC is a cloud ceiling of at least 1,000 feet above the ground and visibility of at least 3 statute miles. VMC is assumed when exceeding the minimum requirement, and IMC is therefore assumed when below the minimum FAA guidelines. VMC and IMC can be determined from ASPM data sets available from FAA or determined from local weather history for the airport vicinity while following some general FAA guidelines. There are more conditional types, such as Marginal (MMC) and Poor Visual (PVC), but VMC and IMC are the two major conditions commonly used in determining an airfield's capacity.

Other inputs in Section 1 include the following:

- Departure-arrival separations (for both VMC and IMC conditions)
- The length of common approach
- Arrival-arrival standard deviation
- Departure runway occupancy time (DROT, abbreviated as Departure ROT in the spreadsheet) standard deviation

Departure-Arrival Separations are defined as the minimum spacing between an arriving aircraft and the runway threshold for a departure to receive clearance to occupy the runway and take off. This value can range from as little as 1 to 5 nautical miles (nm, also noted as "nmiles" on some spreadsheet pages) or more, depending on the surrounding conditions. Even though the default values have both been set at 2.0 nm in this model, the values for VMC and IMC are not always the same.

The **Length of Common Approach** is the distance from the outer marker (the point at which the aircraft is on final approach) to the runway threshold. During this phase of flight, aircraft traveling at different speeds can possibly get closer or further apart as they descend on final approach to the runway. This value is typically between 5 and 10 nautical miles.

Arrival-Arrival Standard Deviation and **Departure ROT Standard Deviation** inputs are determined from actual ATC tower datasets or field observations at specific airfields. The input reflects the variance in consistency of pairs of arriving and departing aircraft in terms of seconds (sec.). This variance helps to sufficiently buffer the necessary separation spacing desired. These are default values that reset when the RESET INPUTS button is clicked, and can be used as a common starting point if data are not available for more detailed analysis. The **Z-value** input is not colored in green like the other inputs as it is a standard statistical value used to achieve a 95 percent confidence level. By using this set value, it is assumed that no more than 5 percent of operations will fail to remain within the assigned separations.

General Inputs, Section 2

The second section of general inputs is focused on the aircraft fleet mix and associated operating specifications, as well as selections regarding the availability and use of runway and taxiways. The Airfield Capacity Spreadsheet Model has expanded the traditional four-category aircraft classification into a seven-category classification system to allow for more specificity of aircraft types and possible interactions with a more diverse fleet mix. The new categories have been discussed for some time, but are not formally agreed upon or used by FAA or the aviation consulting industry. The expanded classification system is used in the model to give the user more variability in identifying the specific fleet mix at the airfield under consideration. A summary of selected aircraft types and their corresponding fleet mix categories which are used in the Airfield Capacity Spreadsheet Model appears separately on the worksheet's "Fleet Mix" tab (Exhibit 10).

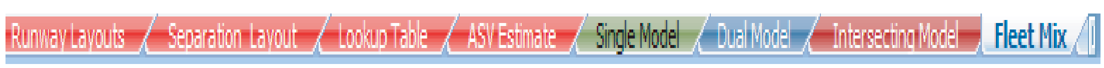


Exhibit 10. Fleet Mix tab.

Exhibit 11 illustrates the second section of general inputs as organized for the Single Runway Model.

At a minimum in Section 2, the user must enter share allocations for the **Operating Fleet Mix** and make selections pertaining to the **Runway, Taxiway** and **Airport Traffic Control Tower** availability. The other inputs can be left as common defaults for a baseline determination of the hourly airfield capacity.

Aircraft Classification New Category	Small - S	Small - T	Small +	Large-TP	Large-Jet	Large-757	Heavy
Previous FAA Category	A	B	C	C	C	C	D
Maximum Gross Takeoff Weight (MTOW)	Less than 12,500 lbs (Single Engine)	Less than 12,500 lbs (Twin Engine)	Between 12,500 lbs and 41,000 lbs	Between 41,000 lbs and 255,000 lbs	Between 41,000 lbs and 300,000 lbs	Boeing 757 Series	More than 300,000 lbs
Operating Fleet Mix Share Allocations	Enter the actual or expected % share for each aircraft class						
	5.0%	0.0%	10.0%	20.0%	60.0%	2.0%	3.0%
Arrival Runway Occupancy Time Time in *Seconds*	Enter the estimated time from touchdown to runway exit						
	32	40	42	45	46	51	55
Average Approach Speeds *Velocity in Knots*	Enter the average suggested manufacturers final approach speed under normal conditions						
	90	100	120	130	135	140	150
Runway Exit Availability (OR)	Excellent or Default		100%	Runway Crossing Delay ?		Yes	90
Full Parallel Taxiway	Full Taxiway		100%	Average Crossing Delay		30	sec
Airport Traffic Control Tower	Yes		Availability	Crossings during Peak Hour		3	Frequency

Exhibit 11. Single Model General Inputs, Section 2.

Explanations of the other inputs in Section 2 are provided below.

The **Operating Fleet Mix** inputs are set up with conditional formats to shade out the aircraft class options that are not selected and to highlight the aircraft classes that are included. The cell values are conditionally formatted to alert the user if the sum does not equal to 100 percent. This alert shows up as a message stating (ADJUST VALUES), and a red summary total percentage appears to the right of the last column, as seen in Exhibit 12.

Fleet Mix Share Allocations	Enter the actual or expected % share each aircraft class						(ADJUST VALUES)	
	9.6%	0.0%	0.0%	0.0%	80.0%	9.5%	9.3%	108.4%

Exhibit 12. ADJUST VALUES alert message.

Fleet mix determinations can be made with FAA ASPM data, airport traffic control tower (ATCT) counts, radar data, or some other available flight-log type data. For those airports without ATCTs, an operational fleet mix should be estimated that considers the airport's based aircraft as well as the itinerant aircraft that operate at the airport.

The goal is to best represent the operational proportions of each aircraft class for use in a probability matrix that determines the likely pairing matches between each possible pair of aircraft classes. The average operational fleet mix probabilities, by aircraft class, are used by the Airfield Capacity Spreadsheet Model for calculations.

For example: if a fleet mix has 50% Small-S aircraft operations and 50% Large-Jet aircraft operations, the probabilities for aircraft pairing would be as follows:

- 25% Small-S leading a Small-S
- 25% Small-S leading a Large-Jet
- 25% Large-Jet leading a Small-S
- 25% Large-Jet leading a Large-Jet

A sample set of aircraft for each aircraft class is provided in Exhibit 13. Aircraft weights are based on manufacturers' suggested Maximum Take Off Weight (MTOW), which can be determined from the manufacturers' specification sheets, www.airliners.net/aircraft-data website, or other sources.

The **Arrival Runway Occupancy Time (AROT)** is specific to each individual aircraft, as is the **Approach Speed**. For purposes of the Capacity Spreadsheet Model, averages of these inputs have been selected as defaults, but the data can be modified if the user has specific information on either of these two inputs. Default settings have been determined through evaluation of common aircraft specifications in each class. They are included in the default values that are linked to the RESET INPUTS button and can be adjusted as needed by the user. Varying airfields will have unique geographic or environmental conditions and/or requirements that will give higher or lower values than the defaults. The user can adjust the values up or down and perform a sensitivity analysis to see the effects of varying the range of inputs for these two factors.

After making the fleet mix selections, the user should examine the **Runway Exit Availability OR Full Parallel Taxiway, and Runway Crossing Delay** input fields. The defaults for the **Runway Exit Availability** and **Full Parallel Taxiway** selections assume that the airfield will have adequate exit availability and a full parallel taxiway to avoid delays on the runway. **Runway crossings** are also assumed to be negligible or minimal, and therefore not causing any noticeable delays under the default conditions. Choosing alternative conditions, such as fewer exits or a partial parallel taxiway, will decrease the calculated airfield capacity by applying a proportionate factor to the original capacity. The applied factors range from 0.75 to 1.0.

IF the user inputs actual or real AROTs into the model, the **Runway Exit Availability** and selection should remain at the default setting and therefore no reduction in capacity would be included in the calculations. The exit reduction is intended for use with the other default inputs. When a true AROT is determined, exit availability has already been factored into the AROT as the actual time until the runway has been cleared.

Additionally, a full parallel taxiway is presumed to be the default case, and if a partial taxiway or no taxiway is selected, the runway occupancy times will therefore be greater and capacity will be diminished. A proportionate factor is applied to the original capacity in conjunction with other limiting factors. The factors range from 0.5 to 1.0.

Aircraft Class Designations		Sample Aircraft
Category	**Small-S**	BE36 - Beech Bonanza 36
Description	Small - Single Engine	C172 - Cessna Skyhawk 172/Cutlass
Weight	< 12,500 lbs	C210 - Cessna 210 Centurion
		PA28 - Piper Cherokee
		PA38 - Piper Tomahawk PA38
		PA46 - Piper Malibu
		PC12 - Pilatus PC-12
		TBM7 - Socata TBM-7
		SR20 - Cirrus SR-20
Category	**Small-T**	BE19 - Beech 19 Sport
Description	Small - Twin Engine	BE20 - Beech 200 Super King
Weight	< 12,500 lbs	BE30 - Raytheon 300 Super King Air
		BE55 - Beech Baron 55
		BE58 - Beech 58
		BE9L - Beech King Air 90
		C425 - Cessna 425 Corsair
		C441 - Cessna Conquest
		C500 - Cessna 500/Citation I
		DHC6 - DeHavilland Twin Otter
		PA44 - Piper Seminole
Category	**Small-+**	BE40 - Raytheon/Beech Beechjet 400/T-1
Description	Small - Twin Engine	C25A - Cessna Citation CJ2
Weight	12,500 - 41,000 lbs	C560 - Cessna Citation V/Ultra/Encore
		C750 - Cessna Citation X
		CL30 - Bombardier (Canadair) Challenger 300
		EMB120-Brasilia
		FA50 - Dassault Falcon/Mystère 50
		GALX - IAI 1126 Galaxy/Gulfstream G200
		LJ35 - Bombardier Learjet 35
		LJ55 - Bombardier Learjet 55
		SBR1 - North American Rockwell Sabre 40/60
Category	**Large - TP**	ATR 42
Description	Large - Turbo Prop	ATR 72
Weight	41,000 - 255,000 lbs	Dash 8 Q100/200
		Dash 8 Q300/400
		Saab 340 *RED denotes weight exception*
Category	**Large - Jet**	Airbus 318/319/320/321
Description	Large - Jet	Boeing 737 Series
Weight	41,000 - 255,000 lbs	DC-9 Series
		MD 80/82/83/88/89
		Gulfstream III/IV/V
		CRJ100/200
		CRJ700/900
		ERJ135/140/145
		EMB170/175/190/195
		CL60 - Bombardier Challenger 600/601/604
Category	**Large - 757**	Boeing 757-200
Description	Boeing 757 Series	Boeing 757-300
Weight	255,000 - 300,000 lbs	
Category	**Heavy**	Airbus 300/310
Description	Heavy - Multi Engine	Airbus 330/340/350
Weight	> 300,000 lbs	Airbus 380
		Boeing 747 Series
		Boeing 767/777
		Boeing 787
		DC-10/MD-11

Source: Landrum & Brown.

Exhibit 13. Aircraft classifications.

The model makes some generalized assumptions as to the impact of not having enough properly spaced exits or not having a full parallel taxiway. The user is asked to make selections in only one of the two input cells for **Runway Exit Availability OR Full Parallel Taxiway.** The main assumption as stated previously is that the airfield will have a full parallel taxiway; **IF NOT,** the user should make a selection in that cell, OR the user can choose to select a runway exit scenario instead.

DO NOT use both selections or the capacity value will be discounted twice by the applied factors.

The final selection in this inputs section is to indicate "Yes" or "No" regarding the availability of an Airport Traffic Control Tower (ATCT). It is assumed in the default case that the airport has an ATCT. In the event that the user selects the "No" option, a 10% reduction to the existing calculated capacity is applied, and separation requirements are adjusted as needed in the case of IMC and dual parallel runways.

Depending on the fleet mix and input conditions, the hourly capacity output will show an operations mix that may already be somewhat balanced or nearly 50 percent arrivals and 50 percent departures. This is not always the case.

If the user does not want to use any further advanced inputs, an assumption can be made that the average hourly capacity would be some proportional combination of the arrivals only capacity and the departures only capacity.

For example: Assume the arrivals only capacity is 40 operations per hour and the departures only capacity is 60 operations per hour

- 36 minutes in arrivals only mode = 24 arrivals
- 24 minutes in departures only mode = 24 departures => **50% mix**

If the user wants to make adjustments to the default buffers and provide more gap spacing between arrivals and permit more departures in mixed operations, the user can click on the "SHOW Advanced Features" radio button (Exhibit 14).

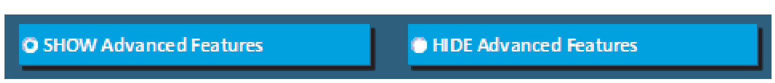


Exhibit 14. SHOW Advanced Features button.

The Advanced Inputs Section is displayed on clicking the SHOW Advanced Features button and is hidden again if the HIDE Advanced Features button is subsequently selected. The advanced input features are described and explained in the next section.

Advanced Inputs, Section 1

The first section of Advanced Inputs allows the user to introduce a buffer to the average arrival to arrival separation and the average departure to departure separation (Exhibit 15). These buffers create more gap spacing, which in turn typically allows for more departures between arrival pairs in mixed operations. The buffer for arrivals can be applied in seconds or miles, depending on which approach is more common to local ATC or which data are available.

Arrival Gap Spacing Buffer	0.0	sec	<----OR---->	Arrival Gap Spacing Buffer	0.0	nmiles
Departure Hold Buffer	10.0	sec				

Exhibit 15. Buffers.

Method #1, as indicated in the model, is known as “gap spacing” and allows manual average increases to the minimum separation between arriving aircraft pairs to permit one or more departures to take off between the pair of arrivals.

The **Arrival Gap Spacing Buffer** should be increased incrementally and the output observed after each change. The user can increase the buffer until the desired level of additional departures is achieved or until the mix between arrivals and departures reaches a certain ratio. During the gap spacing adjustment process, the number of arrivals will decrease as more departures are added. The user should only increase the buffer if the change adds sufficient departures to compensate for fewer arrivals.

The **Departure Hold Buffer** is not meant to be used to try and increase overall capacity; rather it will actually decrease airfield capacity as a certain safety level may require more spacing before departure release based on specific operating conditions.

Advanced Inputs, Section 2

The second section of Advanced Inputs deals with the arrival to arrival separation minima referenced previously and is based on default levels as outlined in FAA EM-78-8A, *Airport Capacity and Delay*. **For the common user, the separation minima default values can be used in most cases and no adjustments are necessary unless specific requirements exist.**

The **Arrival-Arrival Separation Requirements** are input in nautical miles and represent the minimum safe distance between the unique aircraft pairs listed in Exhibit 16. FAA report EM-78-8A, *Airport Capacity and Delay*, provides a set of guidelines for minimum separation distances. Each pair consists of a trailing and leading aircraft. Smaller aircraft are spaced farther behind larger aircraft due to the increased wake vortex from larger aircraft. Separation minima are higher during IMC weather conditions than during VMC weather conditions. Overall minimum spacing defaults are set to 1.9 nautical miles in VMC and 3.0 nautical miles in IMC.

Note: These are minimum separation distances and the resulting capacity outputs represent an optimistic outcome.

If observed average arrival runway occupancy times are less than 50 seconds, 2.5 nautical miles can be used as the alternate minimum separation gap. To use the **Alternative IMC Minimum** value, the user needs to select the "Yes" option to the right of the separation inputs. When the RESET INPUTS button is clicked, the separation defaults will reset to whichever minimum value has been selected.

Arrival-Arrival Separation Requirements *Distance in Nautical Miles (nm)*

Trailing Aircraft	Leading Aircraft	VMC	IMC		
Small-S --- Heavy	Small-S, Small-T	1.9	2.5	2.5	**Alternate IMC Minimum**
Small-S --- Small+	Small +	1.9	2.5	2.5	(if Observed AROT < 50 Seconds)
Large --- Heavy	Small +	1.9	2.5	2.5	**Use 2.5 nm in place of 3.0 nm?**
Small-S --- Small+	Large-TP, Jet	2.7	4.0		Yes
Large --- Heavy	Large-TP, Jet	1.9	2.5	2.5	
Small-S --- Small+	Large-757	3.7	5.0		
Large --- Heavy	Large-757	2.7	4.0		
Small-S --- Small-T	Heavy	4.6	6.0		
Small + --- 757	Heavy	3.6	5.0		
Heavy	Heavy	2.7	4.0		

Exhibit 16. Single Model Advanced Inputs Section 2, showing Arrival-Arrival Separation Requirements and Alternate IMC Minimum.

The user can make suitable adjustments as necessary to increase the arrival-arrival separation requirements to better represent conditional requirements at the airfield under consideration.

Advanced Inputs Section 3

The final Advanced Inputs section is focused on the separation requirements for spacing between departures. The minimum levels used as defaults are also outlined in FAA's EM-78-8A, *Airport Capacity and Delay*. **For the common user the separation minima default values can be used in most cases and no adjustments are necessary unless specific requirements exist.**

The **Departure-Departure Separation Requirements** are input in seconds (as opposed to nautical miles for arrival-arrival separation) and range from 35 seconds in VMC for successive small aircraft to 120 seconds when a small aircraft follows a 757 jet or Heavy jet (see Exhibit 17). Again, this spacing is necessary to protect against the effects of the leading aircraft's wake vortex. Typically, 60 seconds is used as the minimum separation between departures allowing the leading aircraft sufficient time to take off and clear the end of runway while not allowing the following aircraft to enter the leading aircraft's wake vortex. These values are also minimum levels and can be increased if desired or required by local ATC.

Departure - Departure Separation Requirements		*Time in Seconds*	
Trailing Aircraft	Leading Aircraft	VMC	IMC
Small-S --- Small +	Small-S- Small +	35	60
Large -TP --- Large 757	Small-S- Small +	45	60
Heavy	Small-S- Small +	50	60
Small-S --- Small+	Large TP, Large Jet	80	80
Large --- Heavy	Large TP, Large Jet	60	60
Small-S --- Large Jet	Large 757, Heavy	120	120
Large 757, Heavy	Large 757, Heavy	90	90

Exhibit 17. Single Model Advanced Inputs Section 3, showing Departure-Departure Separation Requirements.

All of the Advanced Inputs can be reset to the determined default values by clicking the RESET INPUTS button. RESET INPUTS

Model Outputs

The model output results are the VMC and IMC hourly operations capacity levels that can be used as individual components or a total hourly mix in evaluating the airfield capacity of an airport. The outputs section as outlined in Exhibit 18 estimates the **Arrivals Only Capacity** with or without touch-and-go operations (labeled **Touch-N-Go** or **TNG**), the **Departures Only Capacity**, the **Mixed Ops-Departure Capacity**, and the **Total Mixed Operations Capacity**. As the user changes the inputs, these outputs change in value accordingly.

OUTPUTS			
	VMC	IMC	Average
Arrivals Only Capacity	40	34	39
Arrivals Capacity (including TNG's)	40	34	39
Departures Only Capacity	51	51	51
Mixed Ops - Departure Capacity (including TNG's)	0	0	0
Total Mixed Operations Capacity	40	34	39
Arrivals Percentage	100%	100%	100%

Exhibit 18. Single Model Outputs.

The inclusion of TNG operations occurs when the user inputs a percentage up to 50% in cell D11. A **T-Factor** (touch-and-go factor) is estimated in the General Inputs, Section 1 to allow a maximum value of 1.4 when the maximum 50% input is used. The T-Factor is applied to the calculated arrivals to estimate a new total arrivals capacity. It is assumed that the majority of TNG operations involve flight training and are normally associated with small aircraft. Military aircraft may also perform significant flight training operations and would need to be uniquely accounted for in the fleet mix and airfield operating conditions. Specific focus on military aircraft is not discussed related to using this spreadsheet model.

TNG operations are calculated by the spreadsheet and added equally to both the **Arrivals Capacity (including TNGs)** output and the **Mixed Ops-Departure Capacity (including TNGs)** output, as included in the input by the user. The **Total Mixed Operations Capacity** output assumes arrival priority and includes all achievable departures between arrivals.

Departures Only Capacity only changes when adjustments to the departure-related inputs are increased or decreased. The **Arrivals Percentage** is arrivals hourly capacity divided by the total mixed hourly capacity and includes the TNG operations if they occur.

Single Runway Model: Quick Reference Guide

Step 1: **Click** the RESET INPUTS button to restore all default inputs to base conditions.

Step 2: Determine and **Input** the %VMC if available. Otherwise, use the default. (Note: Exhibit 19 shows input locations for steps 1 through 7).
VMC and IMC capacities are typically cited separately and the overall average may not be necessary, but for determination of the annual capacity or annual service volume (ASV) the split between VMC and IMC will be necessary.

Step 3: **Input** the assumed percent of operations that occur as touch-and-goes.
No adjustments need to be made to the departure-arrival separations, common approach, or standard deviations for a base capacity determination.

Step 4: Determine or estimate, then **Input** the share allocations of the airfield's operational fleet mix.
Remember, the total must add up to 100%, and only the selected aircraft classes will remain fully visible, as those inactive input cells will be shaded.

Step 5: **Adjust** AROTs and Average Approach Speeds if supporting data or operational knowledge is available.
Otherwise, use the default values which provide a usable base set of estimates.

Step 6: **Make selections** with dropdown boxes as to the availability of runway exits, taxiways, and an Airport Traffic Control Tower.

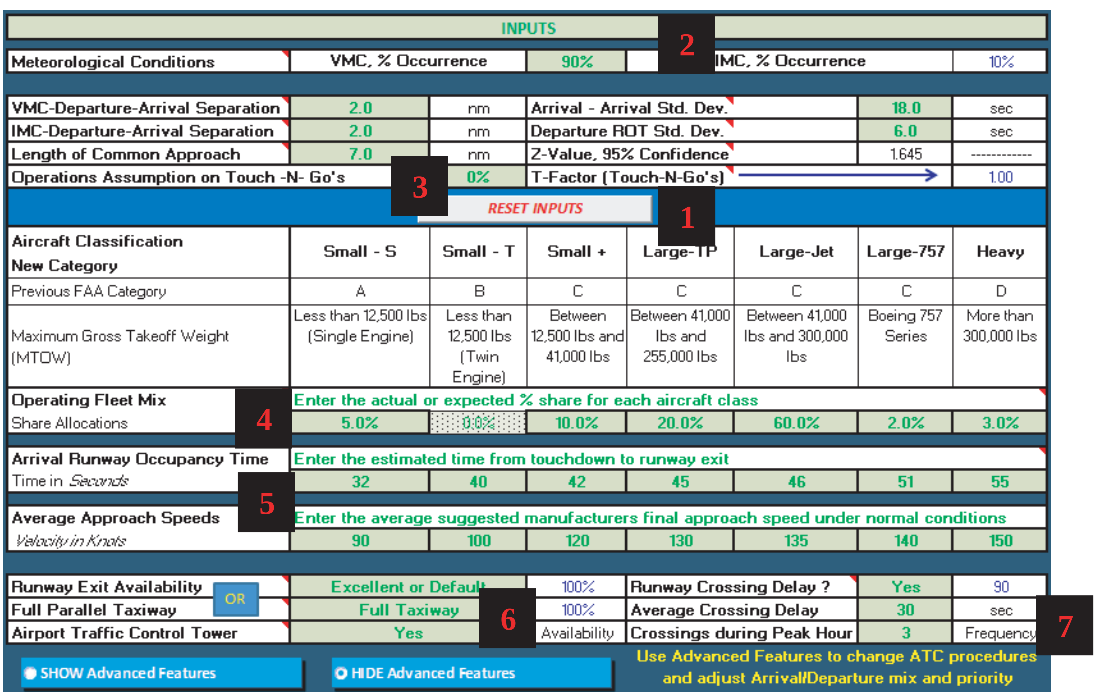


Exhibit 19. Inputs, Single Runway Model.

Step 7: **Make a selection** as to the existence of runway crossing requirements. **Input** assumptions as to the number of crossings that occur in an hour and how long the average delay is in seconds.
No adjustments need to be made to the runway crossing delay if data is unavailable (i.e., keep the input set to "NO" and 0)

Step 8: **Click** the SHOW Advanced Features button to unhide the remaining input cells for further adjustment of the average arrival to arrival separation times and average departure to departure separation times that determine the hourly capacity outputs, as needed (Exhibit 20).

Exhibit 20. SHOW Advanced Features and HIDE Advanced Features buttons.

Step 9: **Adjust** minimum arrival pair separation distances (nautical miles, abbreviated nm or nmiles in the spreadsheets) and minimum departure to departure times (seconds, abbreviated sec) if knowledge of air traffic control guidelines, local requirements and methodology is available and understood (Exhibit 21).
Otherwise, use the default values which provide a usable base set of estimates.

Arrival-Arrival Separation Requirements		*Distance in Nautical Miles (nm)*			
Trailing Aircraft	Leading Aircraft	VMC	IMC		
Small-S --- Heavy	Small-S, Small-T	1.9	2.5	2.5	**Alternate IMC Minimum**
Small-S --- Small+	Small +	1.9	2.5	2.5	(if Observed AROT < 50 Seconds)
Large --- Heavy	Small +	1.9	2.5	2.5	**Use 2.5 nm in place of 3.0 nm?**
Small-S --- Small+	Large-TP, Jet	2.7	4.0		Yes
Large --- Heavy	Large-TP, Jet	1.9	2.5	2.5	
Small-S --- Small+	Large-757	3.7	5.0		
Large --- Heavy	Large-757	2.7	4.0		
Small-S --- Small-T	Heavy	4.6	6.0		
Small + --- 757	Heavy	3.6	5.0		
Heavy	Heavy	2.7	4.0		

Departure - Departure Separation Requirements		*Time in Seconds*	
Trailing Aircraft	Leading Aircraft	VMC	IMC
Small-S --- Small +	Small-S- Small +	35	60
Large -TP --- Large 757	Small-S- Small +	45	60
Heavy	Small-S- Small +	50	60
Small-S --- Small+	Large TP, Large Jet	80	80
Large --- Heavy	Large TP, Large Jet	60	60
Small-S --- Large Jet	Large 757, Heavy	120	120
Large 757, Heavy	Large 757, Heavy	90	90

Exhibit 21. Inputting separation distances and minimum departure to departure times.

At this point all of the major inputs have been made and the results in the outputs section should represent the baseline arrival priority mode capacity and the departure priority mode capacity. Depending on the set of inputs and selections that were used, the operations mix may or may not be balanced.

The model suggests two methods for arriving at a specific operations mix ratio or an optimum capacity level.

The first method is identified as the **Gap Spacing** or gap stretching method, and it increases the average separation gap between each arrival pair to allow for more departures between arrivals. Gap spacing allows the user to achieve a more balanced operational mix, essentially creating a "one in, one out" condition for 50% arrivals and 50% departures (Exhibit 22).

Method #1 for adjusting Arrival/Departure Mix (Gap Spacing)
Gap Spacing allows more time between arrival pairs to permit more than one departure between pairs.

Exhibit 22. Method 1 (gap spacing).

Step 10 (Method #1, Gap Spacing): Adjust the **Arrival Gap Spacing Buffer** by increasing either the *time buffer* (seconds) or the *distance buffer* (nautical miles) until the desired output is achieved (Exhibit 23). Use only one option.
*The Departure Hold Buffer provides safety assurance before a departure is cleared for take off, **but** is not used as a part of the arrival gap spacing method.*

Arrival Gap Spacing Buffer	0.0	sec	<----OR---->	Arrival Gap Spacing Buffer	0.0	nmiles
Departure Hold Buffer	10.0	sec	10			

Exhibit 23. Using Method #1 (Gap Spacing) to adjust the arrival gap spacing buffer.

Step 11 (Method #2): If a specific arrival percentage is desired, the user can take an algebraic approach and proportionally assign time segments where different operating modes would be conducted.

Adjust the share allocations for **Mixed Operations, Arrivals Only,** or **Departures Only** capacities to achieve the desired operations mix (Exhibit 24). Make sure the total sum of the inputs equals 100%. If the total does not add up to 100%, a sum warning (*ADJUST ALLOCATIONS*) will appear in red lettering underneath the heading **VMC Allocations** to alert the user.

Method #2 for adjusting Arrival/Departure Mix (Variable Airfield Operations)
Variable operations permits operating with different capacties (e.g. Departure Priority, and Mixed)
for portions of the design hour.

Arrival Percentage Variance (Portion of Capacity Hour in Mixed/Arr. Priority/Dep. Priority)					
VMC Allocations		0%	Mixed Operations	0.0	min
11		55%	Arrivals Only	33.0	min
		45%	Departures Only	27.0	min
		100%	Total	60	min
Calc. % Arr	32%	0	Arrivals (Mixed)		Average
		17	Arrivals (Only)	17	Arrivals
		0	Departures (Mixed)	35	Departures
		35	Departures (Only)	51	Total

Exhibit 24. Using Method #2 to adjust the arrival gap spacing buffer.

DUAL PARALLEL RUNWAYS MODEL

The dual parallel runways model (Dual Model) is developed in the same manner as the Single Model and therefore estimates hourly capacity using the same assumptions and methodology. All of the formatting and interpretations are the same and the models flow similarly.

A few differences in the models are necessary to accommodate the additional interactions and air traffic rules surrounding two runways operating next to each other in parallel. The Dual Model also introduces a runway configuration caption at the top left of the worksheet (Exhibit 25).The caption includes a box at the far left that indicates the operational scenario selected by the user and four boxes that describe the dependency states of operations in VMC and IMC in the scenario. These two visual sections will help the user determine how to use and interpret the output results.

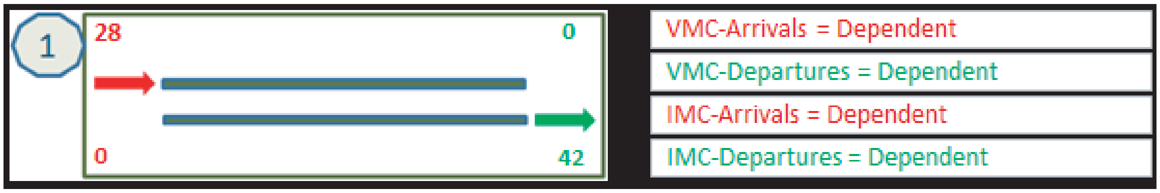


Exhibit 25. Runway configuration caption in Dual Model with Scenario 1 selected.

The Dual Model allows the user to select from eight different operations scenarios (four dependent and four independent). The configuration caption includes scenario number and illustrates arrivals in RED and departures in GREEN. The boxes on the right indicate whether dual simultaneous arrivals or dual simultaneous departures would be permitted based on the weather conditions and runway separation distance (a new input for the Dual Model). A dependent runway pair is not eligible for dual simultaneous operations.

In Exhibit 25, Scenario 1 assumes arrivals only on Runway 1 and departures only on Runway 2. The dual parallel runway configuration is assumed to be dependent in all cases listed, and the example outputs are suggesting 28 arrivals and 42 departures under the given inputs.

In each scenario, the presumption is that the runways are either dependent or independent in relation to each other; however, that is not consistently the case, as simultaneous arrival pairs and simultaneous departure pairs are considered independent at different runway separation distances.

The table in Exhibit 26 provides a list of runway spacing ranges that determine dependency between the two runways for dual simultaneous arrivals or departures. From the table, it is evident that under VMC, a pair of runways can be considered independent for departures yet be dependent in regard to arrivals when the distance is between 700 feet and 2,499 feet.

Under IMC, the same situation results when the distance is between 2,500 and 3,399 feet. The determinations for dependency in the model follow the criteria in this table.

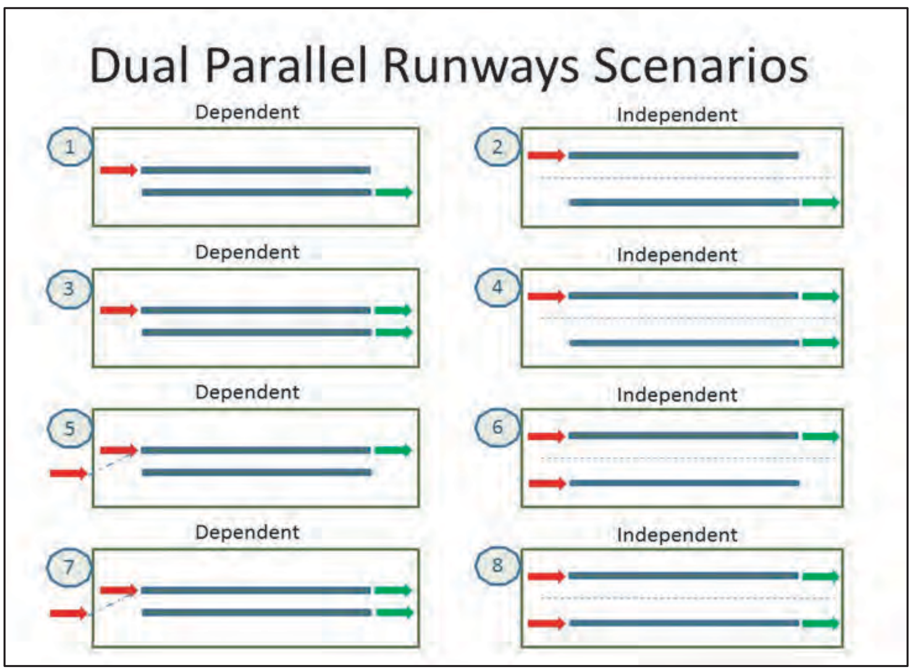
VMC		Parallel Runway Spacing	IMC	
Arrivals	Departures	(distance between centerlines)	Arrivals	Departures
DEP	DEP	less than 700 feet	DEP	DEP
DEP	IND	700 - 2499 feet	DEP	DEP
IND	IND	2500 - 3399 feet	DEP	IND
IND	IND	3400 - 4299 feet	IND*	IND
IND	IND	4300 feet or more	IND	IND

*w/radar, DEP w/o radar

Source: FAA JO 7110.65 Air Traffic Control

Exhibit 26. Parallel runway spacing—ranges under VMC and IMC.

Exhibit 27 portrays the eight scenarios included as options in the spreadsheet model. The dotted line in the even-numbered scenarios suggests an assumption of runway independence and thus independent runway operations can be performed.



Source: Landrum & Brown

Exhibit 27. Dual parallel runways scenarios.

The spreadsheet model for dual parallel runways requires additional inputs (beyond those in the Single Model) to account for the spacing requirements between aircraft as new conditions exist due to the potential simultaneous operations of two runways. Three new inputs make up a *new* General Inputs, Section 1 in the Dual Model. One new input is included in the Advanced Inputs, Section 1. The inputs that appeared in General Inputs Sections 1 and 2 in the Single Model remain the same, but in the Dual Model they are located below the new General Inputs, Section 1 (see Exhibit 28).

New **General Inputs, Section 1** (for Dual Model)

As was suggested in the detailed overview of the Single Model, the user can reset all the default inputs initially by clicking the RESET INPUTS button.

After selecting the VMC and IMC occurrence percentages, the user chooses a **Runway Scenario Selection** (one of the eight scenario configurations for evaluation or comparison). The user must then select whether or not **Divergent Departure Routes** are in place to provide an opening situation for potential simultaneous departures (a Yes/No selection). Next, the user inputs the **Runway Separation Distance** in feet between the centerlines of the two runways to determine, in VMC and in IMC, if operations between them are dependent or independent.

Runway Scenario Selection	1	<--- Select a Dual Parallel Runway Scenario in cell C8		
Divergent Departure Routes	No	15 deg or more	Runway 1 Operations	Arrivals Only
Runway Separation Distance	500	ft	Runway 2 Operations	Departures Only

Exhibit 28. New General Inputs, Section 1 (for Dual Model).

Completing the new inputs section establishes the choice of an evaluation configuration, and conditions are illustrated for visual reference.

Following the new General Inputs, Section 1, the remaining General Inputs sections contain the same inputs and selections as in the Single Model and should be utilized in the same manner.

New **Advanced Inputs Items (for Dual Model), Section 2**

In the Dual Model the user can choose to adjust the inputs in the Advanced Inputs sections. All but one of the inputs in this section of the model are the same as those for the Single Model.

The new input for the Dual Model is a selection as to the **Diagonal Separation Allowed** (Exhibit 29). This is the diagonal distance between a pair of arrivals measured in nautical miles following the axis of the two parallel runways. **Important:** This input is only used if the user has selected either Scenario 3 or Scenario 5 as the **Runway Scenario Selection** in General Inputs, Section 1.

Arrival Gap Spacing Buffer	10.0	sec	<---OR--->	Arrival Gap Spacing Buffer	0.0	nmiles
Departure Hold Buffer	10.0	sec		Diagonal Separation Allowed	1.5	nmiles

Exhibit 29. Selection of diagonal separation allowed (in Dual Model Scenario 3 or Scenario 5).

Depending on the distance between the runways, the guidelines on the diagonal distance suggest increasing diagonal separation as centerline distance increases. The diagonal distances associated with the model options range from 1.5 nm to 3.0 nm.

The diagonal spacing reduces the longitudinal spacing required between a pair of arrivals, but the following pair must still maintain the minimum spacing between the leading pair, just as on a single runway the following aircraft must maintain the separation minimum distance with the leading aircraft.

As was explained in the Single Model, Method #1 or Method #2 can be used to adjust or optimize the operations mix. Method #2 is most appropriate if the user wishes to determine a specific arrivals percentage.

The outputs in the Dual Model are set up in a similar fashion to the outputs in the Single Model, but additional rows have been provided within the table to display capacity estimates for both Runway 1 and Runway 2.

Interpretation and sensitivity analysis using either adjustment method should be conducted in the same manner as in the Single Model. Additionally, the Dual Model provides some basic operational scenarios for comparison, and the user can either use the model to estimate an optimal output (such as two independent runways operating in a balanced mixed flow, Scenario 8) or some other partial operating flow (such as Scenarios 1 through 7).

Outputs from the Dual Model should be comparable to outputs from the Single Model.

For Example:

If the user inputs the same data and makes the same specific selections in the Dual Model and in the Single Model, the results (outputs) should be equivalent. Assume a single runway with optimal mixed operations and Scenario 8, which assumes an independent dual parallel runway configuration with mixed operations on both runways. The Dual Model result should be equal to twice (2x) the Single Model result under the same conditions.

DUAL INTERSECTING OR CONVERGING RUNWAYS MODEL

The Dual Intersecting Runways Model (Intersecting Model) is developed in the same manner as the Single Model and the Dual Model and will therefore estimate hourly capacity using the same assumptions and methodology. All of the formatting and interpretations are the same and the models flow similarly.

A few differences in the Intersecting Model are necessary to accommodate the additional interactions and air traffic rules surrounding two runways operating with an intersection or a closing/opening configuration. Like the Dual Model, the Intersecting Model includes a runway configuration caption at the top left of the worksheet to provide example operating configurations for comparison (Exhibit 30). The visual will help the user determine how to use and interpret the output results.

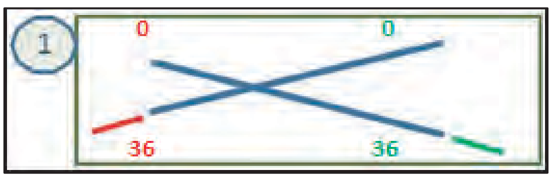


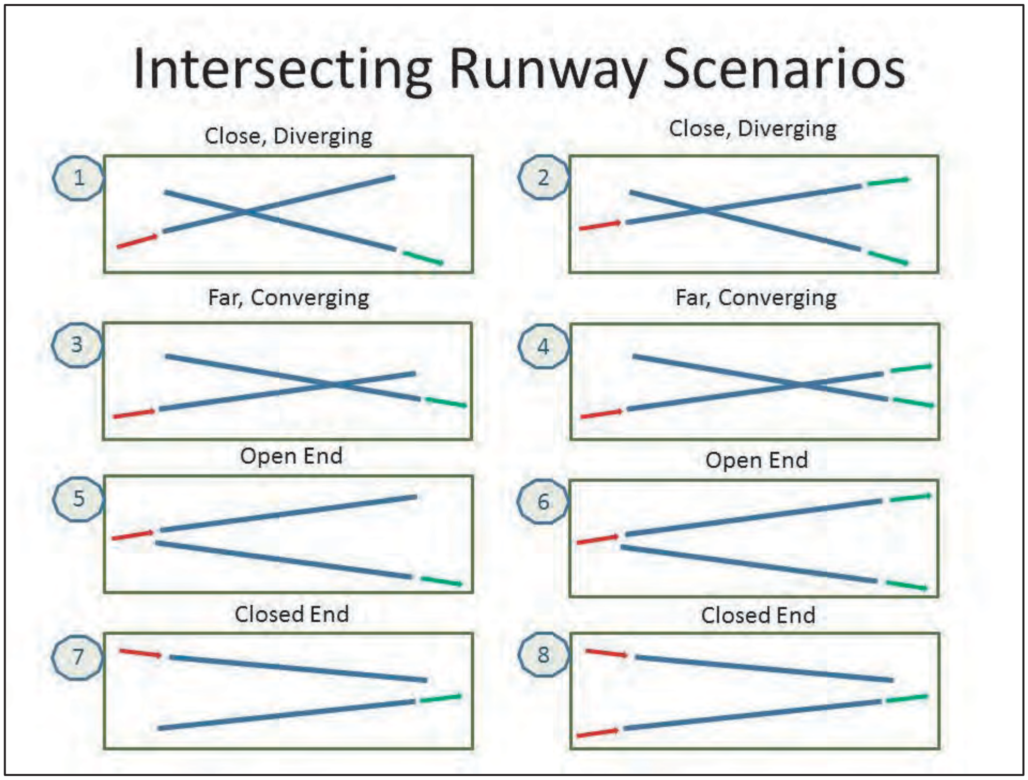
Exhibit 30. Runway configuration caption in Intersecting Model.

The Intersecting Model is set up to allow the user to initially choose from eight different operations scenarios. The chart indicates the scenario number and illustrates arrivals in RED and departures in GREEN.

In Exhibit 30, Scenario 1 assumes arrivals only on Runway 1 and departures only on Runway 2. This dual intersecting runways configuration estimates outputs to be 36 arrivals and 36 departures under the given inputs.

The presumption in the case of intersecting runways is that the runways are dependent in relation to each other, and therefore non-simultaneous runway occupancy guidelines are adhered to in the model assumptions.

Exhibit 31 portrays the eight scenarios included as options in the Intersecting Model.



Source: Landrum & Brown.

Exhibit 31. Intersecting runway scenarios.

Some additional inputs are included in the Intersecting Model to account for the spacing requirements between aircraft, thresholds, and intersections, as new conditions exist due to the potential simultaneous operations of two intersecting runways. Seven new inputs are included as part of this model's General Inputs, Section 1. The inputs that were included in the Single Model as General Inputs, Section 1 and General Inputs, Section 2 are consistent and remain the same, but in the Intersecting Model they are located below the new inputs. The new inputs appear first, at the top of the inputs section.

New **General Inputs, Section 1** (for Intersecting Model)

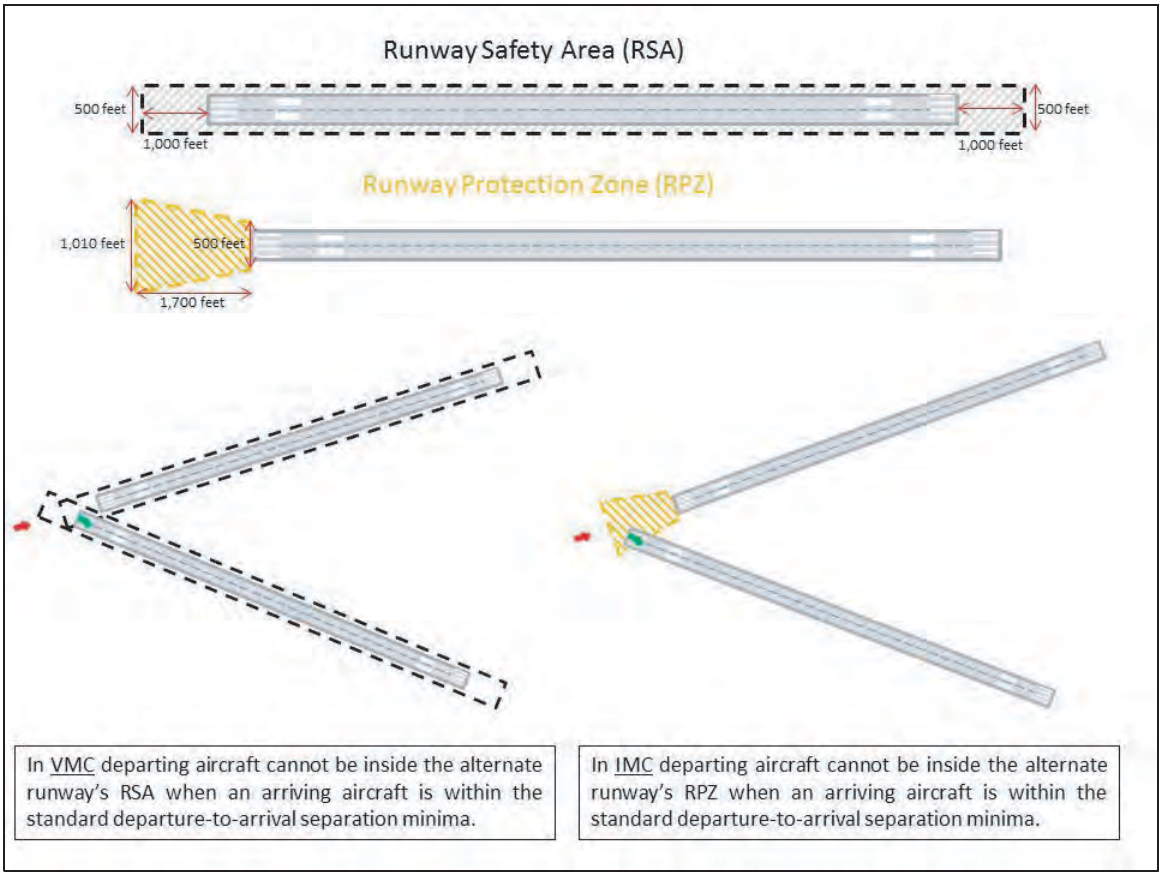
As is true throughout the Airfield Capacity Spreadsheet Model, the user can reset all the default inputs initially by clicking the RESET INPUTS button.

The first selection to be made in this section is to choose one of the eight scenario configurations for evaluation or comparison (see Exhibit 32). This new section asks the user to then input the distance from threshold to intersection on each runway.

Runway Scenario Selection	5	<--- Select an Intersecting Runway Scenario in cell C8			
Distance to Intersection (Rnwy 1)	5,000	ft	Runway 1 (Operations)	Arrivals Only	
Distance to Intersection (Rnwy 2)	6,000	ft	Runway 2 (Operations)	Departures Only	
Is Rnwy 1 departure in Rnwy 2 RSA ?	No		Divergent Departure Routes	Yes	
Is Rnwy 1 departure in Rnwy 2 RPZ?	No		Arrivals Decceleration Rate (avg.)	5.3	ft/sec/sec
Potential In-air conflict at Intersection	No		Departures Acceleration Rate (avg.)	8.0	ft/sec/sec

Exhibit 32. New General Inputs, Section 1, for Intersecting Model.

Next the user selects whether or not departure runway thresholds infringe on the **Runway Safety Area (RSA)** or **Runway Protection Zone (RPZ)** of the other runway, and if **Divergent Departure Routes** are in place to provide an opening situation for potential simultaneous departures. A description of the RSA or RPZ infringements is portrayed in Exhibit 33.



Source: Landrum & Brown.

Exhibit 33. Description of the RSA or RPZ infringements.

The final new inputs are the average estimated deceleration and acceleration rates of arriving and departing aircraft, respectively. These values can be left at the default values of 5.3 feet/sec/sec and 8.0 feet/sec/sec for a diverse fleet mix, or they can be adjusted to a known estimate for a fleet which is predominantly one aircraft type.

After updating the inputs in the new General Inputs Section, the remaining General Inputs sections contain the same material and inputs or selections as in the Single Model and should be utilized in the same manner. The user can also choose to adjust the inputs in the Advanced Inputs sections, which will appear the same as in the Single Model.

Method #1 can be used to adjust or optimize the operations mix in the same way as explained in the Single Model overview. Method #2 can be used as well to determine a specific arrivals percentage.

The Outputs Section in the Intersecting Model is set up similarly to the Outputs Section in the Single Model, but has additional rows within the table to provide capacity estimates for both Runway 1 and Runway 2.

Interpretation and sensitivity analysis using either adjustment method should be conducted in the same manner as in the Single Model. Additionally, the Intersecting Model provides some basic operation scenarios for comparison, and the user can either use the model to estimate an optimal output, such as two intersecting runways operating in a balanced flow with 50 percent arrivals on one runway and the remaining departures on the other runway (Scenario 1).

ANNUAL SERVICE VOLUME (ASV) DETERMINATION

DATA NEEDED:

- Hourly capacity levels (from spreadsheet model)
- % occurrence of meteorological conditions (% VMC, % IMC, etc.)
- Annual and daily traffic volumes
- Peak hour traffic volume

IF actual data are not available, use a best guess or estimate.

Model results provide estimates of hourly capacities, and those values can be used to further estimate the number of aircraft operations that can likely be achieved on an annual basis for planning purposes. The annual capacity or annual service volume (ASV) is a planning metric that is used by airports and airport authorities to plan airside and landside development and financial budgets for master planning and general operations requirements.

In the Airfield Capacity Spreadsheet Model, the tab labeled "ASV Estimate" opens a sheet that incorporates the ASV determination method as shown in the AC (Exhibit 34).

Exhibit 34. ASV Estimate tab.

This method scales up the determined hourly capacities with hourly and daily demand ratios based on relationships between peak demand and annual activity. The following calculation is used to estimate ASV:

$$\mathbf{ASV = C_w * D * H}$$

Where C_w is the weighted average of hourly capacities at their respective percent occurrence over a period of time. The model capacity outputs can be calculated for VMC and IMC, and for other marginal conditionals if the user has a more in-depth knowledge of the air traffic control environment and operating requirements. The ASV model asks the user to input the hourly capacity values determined from the single, dual or intersecting models and also the percent occurrence of those meteorological conditions to arrive at C_w.

D and **H** are the demand ratios which represent the Annual Demand/Avg. Peak Month Daily Demand (D), and the Avg. Peak Month Daily Demand/Avg. Peak Hour Demand (H). Daily traffic activity data for at least the peak month and the annual traffic volume is required to best determine these demand ratios.

Annual data are readily available through the FAA Terminal Area Forecast database online (http://aspm.faa.gov/main/taf.asp); and daily traffic data are also available online in the form of operational counts from the FAA ASPM database (http://aspm.faa.gov/).

Demand ratios should fall within the range of typical results shown in Exhibit 35.

Mix Index	Daily (D)	Hourly (H)
0 - 20	280 - 310	7 - 11
21 - 50	300 - 320	10 - 13
51 - 180	310 - 350	11 - 15

Source: FAA AC 150/5060-5, *Airport Capacity and Delay*, Table 3-2.

Exhibit 35. Table of typical results (demand ratios).

The user will need to determine or make an assumption as to the operating fleet mix at the airport under consideration. The mix index is selected from a dropdown box with three choices, 0–20, 21–50 and 51–180. These values are determined from the following equation:

Fleet Mix Index = %C aircraft + 3(% D aircraft).

C aircraft are designated as Large Aircraft (i.e. Large-TP(Q400) + Large-Jet(B737) + Large-757), and **D** aircraft are designated as Heavy Aircraft such as a B767 or B747.

If the user does not wish to calculate the **D** and **H** demand ratio values, a midpoint assumption can be used from the table of typical results (Exhibit 35) after determining a fleet mix index to use.

The model asks the user to make one final selection, which is to select whether or not to use weighting factors. These weighting factors found in the model allow for additional lower capacity conditions to have a greater impact on the overall average. The use of weighting factors estimates a more conservative final ASV. The weighting factors shown on the “ASV Estimate” tab are sourced from Table 3-1 in the AC.

Determining ASV values using this method is a very common approach for estimating annual airfield capacity at small airports.

GLOSSARY

Airfield Capacity Terms Used in the Prototype Airfield Capacity Spreadsheet Model

Aircraft Class—*A category assignment to all aircraft models that places aircraft in a group with other aircraft of the same weight class. The aircraft classifications used in this capacity model are based on MTOW.*

Approach Speed—*The recommended speed contained in aircraft manuals used by pilots when making an approach to landing. This speed will vary from different segments of an approach as well as for aircraft weight and configuration. (FAA JO 7110.65)*

Arrival to Arrival Separation—*Either the longitudinal spacing provided for by Air Traffic Control and the aircraft pilots between two aircraft on final approach, or the time between sequential arrivals at touchdown.*

Arrival to Arrival Separation Standard Deviation (Delivery Error)—*The average variance of a given set of data/observations for actual separation spacing in comparison to what was intended by Air Traffic Control guidelines and separation minima.*

Arrival Priority—*A mode of airfield operations where departures may occur in a mixed operating mode but priority is always given to the sequenced arrivals and permits the maximum number of arrivals per hour. In a pure arrival priority mode, no departures occur.*

Arrival Runway Occupancy Time (AROT)—*The average time an aircraft or aircraft group occupies the runway during landing, from the time the threshold is crossed until the arrival fully exits the runway.*

Centerline Distance—*The tangential distance between the centerlines of two parallel runways.*

Common Approach Length—*The distance between the arrival runway threshold and the outer marker or the point at which an arrival is considered to be on final approach.*

Converging Runways—*Two runways that do not physically cross or meet, yet approach each other at some point and have interacting approach or departure paths. Depending on traffic flow, the runways may also be considered 'Diverging'.*

Departure to Arrival Separation—*The minimum required separation from threshold to an arrival on approach for a departure to receive clearance for take off.*

Departure Priority—*A mode of airfield operations where departures are given priority and allows for arrivals to occur, but priority is given to departing aircraft unless a safety situation requires an arrival be permitted to land.*

Departure Runway Occupancy Time (DROT)—*The average time a departing aircraft occupies the runway during take off until a clear lift off is reached.*

Dependent Runways—*A pair runways that are configured as either parallel or intersecting and, due to proximity or infringement of protected safety areas, are considered as one runway and do not operate simultaneous departures or arrivals. A dependent runway pair may be dependent for arrivals yet independent for departures.*

Diagonal Separation—*The separation between two aircraft approaching two parallel runways measured from the leading aircraft on route to the first runway, to the trailing aircraft in an arrival pair on route to the second runway.*

Fleet Mix—*A descriptive representation of the types and shares of aircraft performing operations at a given airfield. (e.g., 40% Small-Single Engine, 50% Small-Twin Engine)*

Gap Spacing—*A method of logically adding additional time between arriving aircraft or buffering the intended separation spacing to allow for at least one or more departures to occur. This process helps to achieve a more balanced flow while still maintaining arrival priority.*

IMC—*Instrument Meteorological Conditions (when visibility is less than 3 statute miles and/or the cloud ceiling is less than 1000 feet above ground).*

Independent Runway—*A single runway that is sufficiently distant from any other runway to operate dual simultaneous arrivals or departures and not have any operational conflicts.*

Intersecting Runways—*Two or more runways that cross or meet at some point within their lengths. (FAA JO 7110.65)*

Maximum Gross Take Off Weight (MTOW)—*The maximum gross weight that an aircraft should not exceed to take off safely. Includes fuel, passengers, and cargo.*

Non-Simultaneous Runway Occupancy (NSRO)—*FAA rule that requires that no more than one aircraft occupy a runway at the same time. An arriving aircraft occupies the runway as soon as the threshold is crossed, while a departure may be considered to be occupying the runway from the time it enters the runway until either a certain altitude above the runway is reached during take off or when the departure crosses the end threshold.*

Runway Crossing Demand—*A measurable requirement for crossing the runway to other runways, taxiways, or terminals. Assumes that no other route avoiding runway occupancy is available.*

Runway Protection Zone (RPZ)—*According to AC 150/5300-13 the RPZ is trapezoidal in shape and centered about the extended runway centerline. The central portion and controlled activity area the two components of the RPZ. The RPZ dimension for a particular runway end is a function of the type of aircraft and approach visibility minimum associated with that runway end. Table 2-4 in AC 150/5300-13 provides standard dimensions for RPZs. Other than with a special application of declared distances, the RPZ begins 200 feet (60 m) beyond the end of the area usable for take off or landing. With a special application of declared distances (see Appendix 14 of AC 150/5300-13), separate approach and departure RPZs are required for each runway end.*

Runway Safety Area (RSA)—*A defined surface surrounding the runway prepared, or suitable, for reducing the risk of damage to airplanes in the event of an undershoot, overshoot, or excursion from the runway. The dimensions of the RSA vary and can be determined by using the criteria contained in AC 150/5300-13, Airport Design, Chapter 3. Figure 3–1 in AC 150/5300-13 depicts the RSA. (FAA JO 7110.65)*

Runway Threshold—*The official beginning or end of a runway marked by a series of 6 to 16 parallel white rectangular markings running in the direction of the runway. The runway threshold also starts the beginning of the Runway Protection Zone.*

Standard Deviation—*A measure of how much variance occurs within a dataset or how much spread exists around a mean or average (or the average distance from the center point for all points around that point).*

Touch-and-Go—*A pair of operations when an arrival makes a touchdown onto the runway and then immediately takes off again without stopping. The operational pair is counted as one arrival and one departure for a total of two (2) operations.*

VMC—*Visual Meteorological Conditions (when visibility is at least 3 statute miles and the cloud ceiling is at least 1000 feet above ground).*

CONCLUSION

Model Limitations

While the model provides for significant input capabilities for a variety of items noted previously, if the airfield configuration is not in the model and/or the airfield is operated in many different configurations, the Airfield Capacity Spreadsheet Model would not reflect a total combined hourly capacity. The model's results present the following information for visual meteorological conditions, instrument meteorological conditions, and an average condition:

- Arrivals only capacity (with and without touch-and-go activity)
- Departures only capacity (with and without touch-and-go activity)
- Total mixed operations

The model does not allow for the results to be combined in any way for when an airfield is operated in these capacities over the course of an hour, day, or year. The Airfield Capacity Spreadsheet Model also does not allow some of the features of detailed simulation modeling in terms of importing schedule or ASPM data.

Recommendations for Further Work

The Prototype Airfield Capacity Spreadsheet Model presents a first step toward a simplified version of the ACM and more fidelity than the current AC methodologies provide. With additional resources, the models could be expanded to allow for additional user inputs to depict more airfield operational conditions. It should be noted that a more detailed version of the models would also require the user to have significantly more data and knowledge of the airfield's operating conditions.

APPENDIX B

ESSENTIAL REFERENCES AND DATA SOURCES

Appendix B includes a list of essential references for airfield capacity analysis and a list of sources of information about each of the 21 capacity factors.

ESSENTIAL REFERENCES

This list of essential references for airfield capacity analysis includes FAA documents, airfield capacity documents, FAA Air Traffic Control orders and manuals, international airfield capacity documents, future technologies and systems, data sources, models, government and university documents and papers.

1. FAA Airfield Capacity Documents

1.1 Federal Aviation Administration: Office of Airport Planning & Programming, Planning & Environmental Division (1983). *Advisory Circular 150/5060-5, Airport Capacity and Delay* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/advisory_circular/150-5060-5/150_5060_5.pdf.

This document contains instructions and steps to compute the airport capacity and aircraft delay for airport planning and design purposes. This circular is primarily intended for airport planners. The throughput method is used to calculate the airport capacity and aircraft delay. These calculations can be used over 19 runway use configurations with multiple arrival streams restricted to parallel runway configurations. For most calculations, the airport is assumed to have at least one ILS-equipped runway, in addition to air traffic control facilities and services to conduct operations even in a radar environment. "Missed approach protection is assured for all converging operations in IFR weather conditions," which are assumed to occur 10% of the time. It is assumed that for 80% of the time, an airport is operated with the runway-use configuration which produces the greatest hourly capacity. Chapter 5 identifies (then available) computer models for runway capacity and aircraft delay analyses, which include SIMMOD, ADSIM, and the FAA Airfield Capacity Model (ACM).

1.2 Federal Aviation Administration & The MITRE Corporation (2007). *Capacity Needs in the National Airspace System, 2007–2025* [PDF document]. Retrieved from http://www.faa.gov/about/initiatives/nextgen/defined/why/cap%20needs%20in%20the%20NAS.pdf.

This report is "an assessment of the future capacity of the Nation's airports and metropolitan areas," trying to identify the locations with the highest need for increased capacity (the airports in the metropolitan region.) This report is intended for air traffic management personnel. Future operations forecasts were generated using the Terminal Area Forecast (TAF) version 2005, prepared by the FAA Office of Aviation Policy and Plans (APO), and Future Air Traffic Timetable Estimator (FATE)[1], a socio-economic model developed by MITRE CAASD. TAF predicts future operations on an airport-by-airport basis. The Enhanced Airfield Capacity Model (E-ACM) was also used to calculate "the average number of arrivals and departures that can be expected during busy periods at an airport based on air traffic control (ATC) procedures, including separation minima, and the probabilistic characteristics of aircraft performance." This analysis factored improvements affecting runway capacity such as new/extended runways, new/revised control procedures, and redesigned airspaces, most of which were available from

[1] Bhadra, D., J. Gentry, H. Brendan, & M. Wells (2005). Future Air Traffic Timetable Estimator. *Journal of Aircraft, 42(2)*, 320–8.

Operational Evolution Plans. The existing environmental restrictions impacting runway capacity, such as noise abatement procedures, were assumed to exist for the duration of the forecast.

1.3 U.S. Department of Transportation, Federal Aviation Administration, & The MITRE Corporation (2004). *Airport Capacity Benchmark Report 2004* [PDF document].

This report provides benchmark values for capacity, defined as "the maximum number of flights an airport can routinely handle in an hour, for the most commonly used runway configuration in each specified weather condition," at the 35 airports listed in the FAA's Operational Evolution Plan (OEP) version 5.0. For each airport, capacity for three different weather scenarios (Optimal or VFR conditions; IFR conditions; and Marginal, which is halfway between VFR and IFR conditions) is calculated. "These benchmarks are estimates of a complex quantity that varies widely with weather, runway configuration, and the mix of aircraft types. Capacity benchmarks assume there are no constraints in the en route system or the airport terminal area." The benchmark values are the sum of (maximum) number of takeoffs and landings per hour that are possible under the conditions, if the demand is present. The frequency of the three weather conditions at each airport was determined using the FAA Aviation System Performance Metric (ASPM) database data. This analysis factored technical and procedural improvements affecting runway capacity such as Simultaneous Offset Instrument Approaches (SOIA), Standard Terminal Automation Replacement Systems (STARS), Traffic Management Advisor (TMA) and Area Navigation (RNAV), most of which were available from Operational Evolution Plans. This report does not, however, explicitly mention the methodology or model used for operation forecasts. This report is intended for air traffic management personnel.

1.4 The MITRE Corporation (1978). *Parameters of Future ATC Systems Relating to Airport Capacity/Delay* (Report No. FAA-EM-78-8A). Washington, DC: Andrew Haines.

This report presented a model to quantify the impact of Wake Vortex Advisory/Avoidance Systems (VAS/WVAS) and the Terminal Area Metering and Spacing (M&S) tools on the spacing on final approach. Of particular interest are tables 3-2 and 3-3. They provide (then) observed and predicted minimum separation under saturated VFR conditions for arrivals and departures. However, these minimum separation values continue to be current. The aircraft classes defined in the model (small, heavy, large) continue to be current.

2. FAA Airspace and Air Traffic Control (ATC) Orders and Manuals

2.1 U.S. Department of Transportation & Federal Aviation Administration (2010). *Order JO 7210.3X Facility Operation and Administration* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/Order/FAC.pdf.

"This order provides instructions, standards, and guidance for operating and managing air traffic facilities." Of particular interest are sections 6-7 (User Request Evaluation Tool URET), 8-2 (NAS En Route Automation Procedures), 10-7 (Airport Arrival Rate AAR), 17-8 (Monitor Alert Parameter), 17-9 (Ground Delay Program), 17-10 (Ground Stop[s]), and 17-14 (Severe Weather Avoidance Plan SWAP).

2.2 U.S. Department of Transportation & Federal Aviation Administration (2010). *Order JO 7110.65U Air Traffic Control* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/Order/ATC.pdf.

"This order prescribes air traffic control procedures and phraseology for use by persons providing air traffic control services." It covers procedures for various types of flights, flight plan information (its needs and type of information), flight strips, communications, signals, and reporting information. Of particular interest are sections 2-1-4 (Operational Priority), 2-1-19 (Wake Turbulence), 2-1-27 (TCAS

Resolution Advisories), 2-1-28 (RVSM Operations), 2-8-2 (Arrival/Departure Runway Visibility), 3-1-6 (Traffic Information), 3-1-7 (Position Determination), 3-1-11 (Surface Area Restrictions), 3-3 (Airport Conditions), 3-8 (Spacing and Sequencing), 3-9 (Departure Procedures and Separation), 3-10 (Arrival Procedures and Separation), 4-8 (IFR Approach Clearance Procedures), 5-5 (Radar Separation), 6-2 (Non-Radar Initial Separation of Successive Departing Aircraft), 6-3 (Non-Radar Initial Separation of Departing and Arriving Aircraft), 6-4 (Longitudinal Separation), 6-5 (Lateral Separation), 6-6 (Vertical Separation), and 7-2 (Visual Separation.) This order is intended for air traffic control personnel and pilots.

2.3 U.S. Department of Transportation & Federal Aviation Administration (1993). *Order JO 7110.98A Simultaneous Converging Instrument Approaches (SCIA)* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/Order/ND/7110.98A.pdf**.**

This order defines the operational criteria and authorized procedures for conducting simultaneous instrument approaches on converging runways. SCIA procedure is permitted under operating conditions which include operational control tower, operational radar, ILS on each runway, and non-intersecting final approach courses. This procedure permits straight-in approaches only. Converging approaches cannot be conducted simultaneously on intersecting runways for decision heights lower than 1,000 ft or visibility less than 3 nm. This order is for aiding air traffic control personnel.

2.4 U.S. Department of Transportation & Federal Aviation Administration (1995). *Order 7110.110A Dependent Converging Instrument Approaches (DCIA) With Converging Runway Display Aid* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/Order/7110.110A.pdf.

SCIA procedures are sometimes not applicable for decision heights lower than 1,000 feet. To address this concern, increasing "airport capacity in IFR weather conditions for airports with converging intersecting or nonintersecting runways," this order identifies the DCIA procedure. This procedure makes use of staggered approaches and accounts for missed approaches by aircraft on two converging approaches occurring within two minutes. DCIA procedure is permitted under operating conditions which include operational control tower, operational radar and ARTS, operational CRDA tool, ILS / MLS on each runway, operational navigational aids, and an open communications link between pilot and controller. The final approach courses need to be non-intersecting with the included angle between the runway approach courses between 45 degrees and 120 degrees. Appendix 1 provides the stagger distances and restrictions for various decision heights, runways configurations, and distance to intersection. This order is enacted for aiding air traffic control personnel.

2.5 U.S. Department of Transportation & Federal Aviation Administration (2000). *Order JO 7110.118 Land and Hold Short Operations* [PDF document]. Retrieved from http://www.faa.gov/documentLibrary/media/Order/7110.118.pdf

Previous defined simultaneous operations on intersecting runways (SOIR) included landing and holding short of an intersecting runway. This order (LAHSO) expands on SOIR to include holding short of taxiway, holding short of approach/departure flight path and holding short of predetermined points on the runway (other than on a runway or taxiway). For commercial flights, LAHSO operations are permitted under certain conditions, which include 5 miles or greater visibility (unless PAPI/VASI-equipped runway), 1,500 ft decision height, and on a runway with electronic/visual glide scope indicator. Appendix 1 provides a table for identifying aircraft that can successfully conduct LAHSO procedure based on the available landing distance. This order is for aiding air traffic control personnel.

2.6 U.S. Department of Transportation & Federal Aviation Administration (2008). ***Order JO 7110.308 CHG 1.5 NM Dependent Approaches to Parallel Runways Spaced Less Than 2500 ft Apart*** **[PDF document]. Retrieved from** http://www.faa.gov/documentLibrary/media/Order/JO7110.308CHG%201.pdf.

"This type of dependent instrument approach can be conducted for airports with specific centerline separations and threshold staggers. The lead aircraft of the dependent pair is restricted to being small or large aircraft weight type and is cleared to the lower approach. The geometry of the approach, with small or large aircraft leading on the lower approach, as well as the lateral separation between the two approaches, provide wake turbulence avoidance necessary for this reduced separation dependent approach operation. Lateral separation between the two approaches contributes to wake avoidance. In addition, a small glide path height difference may be necessary, especially at distances of 7 or more nautical miles from touchdown, to ensure the trailing aircraft is at or above the height of the leading aircraft in the reduced separation pair. The required glide path height can be achieved through displaced landing thresholds or through small glide path angle differences that are permitted within the constraints of precision approaches." Table TBL-A-1 in Appendix 1 identifies the runway pairings where these approaches can be conducted and lists various glide path values for approaches at these runways. This order is for aiding air traffic management and air traffic control personnel.

2.7 U.S. Department of Transportation & Federal Aviation Administration (2008). ***Order N JO 7110.478 Interim Procedures for A380 Proving and Promotional Flights*** **[PDF document]. Retrieved from** http://www.faa.gov/documentLibrary/media/Notice/ND/N%20JO%207110.478.pdf.

This cancelled order had defined the in-trail separation applicable for the Airbus A380 aircraft to account for possible larger wake vortices. An aircraft trailing the A380 en-route was required a minimum of 5 nm separation. A minimum of 10 nm spacing was required when transitioning to terminal airspace. Within terminal airspace, separation of 6 nm (for heavy aircraft behind A380), 8 nm (for large aircraft behind A380) and 10 nm (for small aircraft behind 380) were required. Operations on parallel runways less than 2,500 ft apart were to be reduced to single runway operations to account for wake turbulence. This order was for aiding air traffic control personnel. This order has not been superseded by another order.

2.8 Federal Aviation Administration (2010). ***Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures*****. Retrieved from** http://www.faa.gov/air_traffic/publications/ATpubs/AIM/

"This manual is designed to provide the aviation community with basic flight information and ATC procedures for use in the National Airspace System (NAS) of the United States." "It also contains items of interest to pilots concerning health and medical facts, factors affecting flight safety, a pilot/controller glossary of terms used in the ATC System, and information on safety, accident, and hazard reporting." Of particular interest here are sections 3-1 (General), which highlights VFR minimums; 3-2 (Controlled Airspace), which highlights the operating rules for various airspaces; 4-4 (ATC Clearances and Aircraft Separation), which identifies role of pilot for implementing separation, 5-2 (Departure Procedures); 5-3 (En Route Procedures); 5-4 (Arrival Procedures); and 5-5 (Pilot/Controller Roles and Responsibilities). The primary audience for this manual is aviators.

3. International Airfield Capacity Documents

3.1 National Air Traffic Services, Ltd. (2003). *A Guide to Runway Capacity for ATC, Aircraft and Airport Operators*. West Drayton, Middlesex UK: Richard Everitt.

This guide is intended for air traffic controllers, airport personnel, and aircraft operators. It explains (then) current issues affecting runway capacity at the UK's major airports, the process of assessing a runway's capacity operates, and includes and an overview of (then) planned developments to maximize runway capacity. It explains, using layman's terms and analogies, the key factors affecting runway capacity, such as runway configuration, wake vortex separation, and aircraft sequencing. UK separation standards for approach (3nm radar separation; 2.5 nm final approach separation) are available in this section. The process to determine runway capacity is also described at a very high level. This includes simulation of delays under full capacity using actual data on arrivals/departures, aircraft, and time-on-ground. (Then) future technologies identified in the guide were time based (4D) separation on final approach, precision landing aids, wake vortex detection systems, spacing tools, departure metering tools, CAT III MLS system, Advanced Surface Movement Guidance and Control Systems, and Runway Incursion Monitoring & Conflict Alerting Systems.

4. Future Technologies and Systems

4.1 Joint Planning and Development Office (2010). *Joint Planning and Development Office*: Making NextGen a Reality. Retrieved from http://www.jpdo.gov/**.**

4.2 Federal Aviation Administration (2008). Operational Evolution Partnership. Retrieved from http://www.jpdo.gov/library/20070726AllHands/20070727_JPDOAllHandsMeeting_OEP_Sypniewski_FINAL.pdf.

4.3 Federal Aviation Administration: NextGen Integration and Implementation Office (2009). *FAA's NextGen Implementation Plan 2009* [PDF document]. Initially retrieved from http://www.faa.gov/about/initiatives/nextgen/media/ngip.pdf**. This document is updated annually. At time of publication, the current document was available from** http://www.faa.gov/nextgen/implementation/media/NextGen_Implementation_Plan_2012.pdf.

4.4 Joint Planning and Development Office (2009). *Concept of Operations for the Next Generation Air Transportation System* version 3.0 [PDF document]. Retrieved from *http://www.jpdo.gov/library/NextGen_ConOps_v3%200.pdf***.**

5. Data Sources

5.1 Federal Aviation Administration (2010). *FAA Aviation System Performance Metrics* (ASPM). Available at http://aspm.faa.gov/aspm/entryASPM.asp**.**

The Aviation System Performance Metrics (ASPM) provides data on IFR flights to and/or from major airports (approx 77); and all flights by specified carriers (approx 22). Flights include those involving international and domestic airports. The ASPM data includes: airport weather (VMC, MIMC, IMC), runway configuration, declared arrival rates, and declared departure rates. Online access to the ASPM system requires a registered user name and password, which may be requested from FAA by completing an Access Request at https://aspm.faa.gov/main/sysMailTo.asp?area=aspm.

5.2 Federal Aviation Administration (2010). *FAA Airline Service Quality Performance System (ASQP).* Available at https://aspm.faa.gov/asqp/sys/.

The Airline Service Quality Performance System (ASQP) includes data provided by the airlines on a flight-by-flight basis from airlines that carry at least 1% of all domestic passengers. The number of airlines that meet this criterion has varied from 10 to 20 over the past two decades. Actual and scheduled time is available for gate departure and gate arrival. The airlines also provide the actual wheels-off time so that taxi-out time can be computed and wheels-on time so that taxi-in time can be computed. In addition, the airlines provide causal data for all flights arriving 15 minutes past their scheduled arrival time. The data is available from June 2003 and is updated on a monthly basis. The causes of delay categories are Airline, Extreme Weather, National Aviation System, Security, and late arriving flight. Online access to the ASQP system requires a registered user name and password, which may be requested from FAA by completing an Access Request at https://aspm.faa.gov/main/sysMailTo.asp?area=asqp.

5.3 Federal Aviation Administration (2010). *FAA Operations Network (OPSNET).* Available at https://aspm.faa.gov/opsnet/sys/.

Operations Network (OPSNET) provides data on air traffic operations and delay data. All FAA ATC facilities (with the exception of flight service stations [FSS]) record OPSNET data, which is provided to the FAA ATO System Operations, Quality Assurance (QA) on a daily basis. The ATCSCC QA then processes the data and stores them into the OPSNET database.

OPSNET records the following information and data: Airport Operations (IFR itinerant and VFR itinerant operations [arrivals and departures], local operations at the airport as reported by air traffic control towers [ATCTs]; tower operations (IFR and VFR itinerant operations [arrivals and departures], IFR and VFR overflights, and local operations worked by the tower); TRACON operations (IFR and VFR itinerant operations and overflights worked by the TRACON); total terminal operations (total operations worked by any facility based on the functions at the facility); ARTCC operations (domestic and oceanic departures and overflights and total aircraft handled); facility information (facility name and type, region, state, and hours of operation for each air traffic control facility); and delays (reportable delays).

To access OPSNET data, users require a login. A user name and password may be requested from FAA by completing an Access Request at https://aspm.faa.gov/main/sysMailTo.asp?area=opsnet. Without a login, users can access the official count released to the public from Air Traffic Activity System (ATADS), which provides data after the 20th of the month for the previous month.

5.4 Federal Aviation Administration (2010). *FAA Air Traffic Activity Data System (ATADS).* Available at https://aspm.faa.gov/opsnet/sys/Main.asp?force=atads.

ATADS data is OPSNET data that is made available after the 20^{th} of the month for the previous month. See discussion OPSNET above. Access to ATADS data does not require a registered user name and password.

5.5 Federal Aviation Administration (2010). *FAA Terminal Aerodroms/Airport Forecast (TAFs).* Available at http://weather.noaa.gov/weather/taf.shtml.

The Terminal Aerodrome/Airport Forecast (TAF) provides weather forecast information. TAFs use similar encoding to METAR reports (*message d'observation météorologique pour l'aviation régulière*/ meteorological observation message for routine aviation). TAFs apply to a five statute mile radius from the center of the airport runway complex. Generally, TAFs can apply to a 9- or 12-hour forecast; some TAFs cover an 18- or 24-hour period. TAFs for some major airports cover 30-hour periods.

5.6 Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics (2011). ***Airline and Airport Information*****. Available at** http://www.bts.gov/programs/airline_information/.

The Bureau of Transportation Statistics (BTS) provides data and statistics on the performance and finances of the air transportation system. This information is derived from FAA data, ASPM, ASQP, and OPSNET, as well as Form 41 data provided by airlines on a monthly/quarterly basis.

BTS Airline and Airport data and statistics include: air traffic (air traffic hubs); aircraft: types, acquisition dates and operating status (available seat-miles, baggage fees, distance between airports); economic research (employment); fares (domestic airfares reported by route); financial statistics (flights, freight, fuel cost and consumption, and load factor); on-time performance; operating profit/loss; operating revenue; passengers; passengers denied confirmed space report; new reservation cancellation/change fees by airline; revenue passenger-miles; and tarmac times.

5.7 Federal Aviation Administration (2010). ***Performance Data Analysis and Reporting (PDARS).*** **Available on request from FAA.**

PDARS data and measurements are based on the processing of radar track and flightplan data collected from Automatic Radar Terminal System (ARTS) computers at the TRACONs, and data collected from the host computers at the ARTCCs. This data provides more details of tracks flown than the Enhanced Traffic Management System (ETMS) or its commercial ASD Feed (used in the industry).

The types of information generated from PDARS data include: travel times within geometric areas (sectors, facilities, etc.); travel times for routing segments (arrival fix to runway, runway to departure fix, facility boundary to/from runway, etc.); flow counts over user-defined points; throughput counts for airports, sectors, etc.; groundspeed distributions at user-defined times and areas; and identification of aircraft deviating from a prescribed procedure.

5.8 Federal Aviation Administration (2010). ***Airport Surface Detection Equipment, Model X (ASDE-X).*** **Available on request from FAA.**

ASDE-X data provides track and identification data for aircraft and equipped vehicles on the airports surface as well as aircraft within approximately 5 miles of the airport.

The core ASDE-X track data includes a radar sensor and a multilateration sensor capable of receiving Automatic Dependent Surveillance—Broadcast (ADS-B) from the aircraft. The ASDE-X Multiprocessor subsystem combines independent surveillance data from the radar subsystem with cooperative and dependent data from the multilateration subsystem to provide a single target with Flight ID for display to air traffic control. The multiprocessor subsystem may also integrate data from Automated Radar Terminal System (ARTS) and the Standard Terminal Automation Replacement System (STARS) as well as the Airport Surveillance Radar (ASR), dependent on the implementation chosen for a given site. In 2010, 35 major airports had ASDE-X equipment installed.

The types of information generated from ASDE-X surface trajectory data include: travel times within geometric areas (e.g., ramp, taxiway, runway); hold times (e.g., gate, ramp spot, departure runway queue); flow counts at specified locations (e.g., ramp spot, runway threshold); throughput counts for gates, runways, taxiways and airports; groundspeed distributions on approach, departure, runways, taxiways and ramps; and identification of aircraft deviating from a prescribed procedure.

6. Models

6.1 LMI Government Consulting (2009). *Catalog of Models for Assessing the Next-Generation Air Transportation System* (Report NS802T2). Washington, DC: Dou Long, Shahab Hasan, Antonio Trani, & Alan McDonald.

This report reviews a comprehensive list of aviation models. The models are separated into two broad categories—airport and airspace—and minor categories: runway, airfield, terminal, and network of airports.

The authors note the strength of the runway models is “their ability to explore a multitude of airport scenarios in a short amount of time. By design, these models lack airfield and airspace network representation in order to keep the input requirements to a minimum. The runway models make simplifying assumptions about runway operational procedures. The vast majority of them rely on a separation matrix approach to estimate the capacity of a runway configuration for a given set of airport conditions (weather, available ATC technology, etc.).” The authors believe these models suffer from the potential inability to accurately predict airfield capacity influenced by other airport airside components.

The models, representing airfield and aircraft state variables and processes, were found to be more realistic because of their integral network connectivity. The authors note that it is unclear “if the current models would be able to model complex and adaptive air traffic flow management procedures for ground operations that are affected by far-away airports or ground-hold decisions due to airspace restrictions. Some of the tools reviewed had scripting capabilities that provide room to reassign aircraft to runway queues based on dynamic traffic conditions. But the elements to handle optimization tasks related to ground holds and system-wide ground path optimization driven by far-away events expected in NextGen seem difficult to model. Some models support unique procedures such as deicing rules and limited optimization of paths on the ground.”

The aircraft behavior in different network type models varied. Most models seemed to have adopted a simplistic approach to model aircraft behavior using an implicit specification of the aircraft performance driven by waypoint flight trajectories with time tags, observed routes, and speeds. The authors also note that “the correlation between simulation framework complexity and aircraft detailed specification in every model is very evident. The runtimes for these models vary significantly as the complexity of the aircraft and ATC model increases. Some of the models can execute a NAS-wide run in a few minutes. Others require many hours (or even days) to run a scenario with thousands of flights.”

The discrete-event, agent-based, simulation models for terminal (or STARS in) were found to provide a better level of fidelity of flights. These models were scalable to model single airports or hundreds of airports, including details of the terminal airspace. The authors noted that the runtimes could vary substantially among models. For example, it is not uncommon to find that some of the models take 10 to 20 interactions to execute the same airspace scenario if the conflict resolution procedures are turned on in the model.

6.2 Massachusetts Institute of Technology: International Center for Air Transportation (1997). *Existing and Required Modeling Capabilities for Evaluating ATM Systems and Concepts*. Cambridge, MA: A.R. Odoni, J. Bowman, D. Delahaye, J.J. Deyst, E. Feron, R.J. Hansman, K. Khan, J.K. Kuchar, N. Pujet, & R.W. Simpson.

This report assessed the strengths and weaknesses of (then) existing fast-time models and tools for the study of ATM systems and concepts and helped identify and prioritize the requirements for the development of additional modeling capabilities in the (then) near future. The models reviewed in this report have nine categories.

The authors found that capacity and delay models, as a group, represented the most advanced and accurate models. They note, however, that these models have four main problems: lack of familiarity, extensive resources required to run these models, lack of adaptability to model future operations (since improved), and lack of environmental validity.

For conflict detection and resolution models, the authors found that the models typically used specified flight plans or randomly generated flight plans (based on desired traffic density.) The aircraft dynamics in the model were simple and generic. Conflict detection models were rule-based on simple geometrical criteria, such as miss distance or penetration of safety buffers around each aircraft. Only a couple of models were found to include the capability to model trajectory uncertainty.

For models of human factors and human/automation modeling, the authors note that it is important to consider the validity and flexibility of a model vis-à-vis different applications. "A microscopic model like MIDAS provides a very detailed description of how the human operates and can provide insight into where bottlenecks are and how performance could be improved. However, whether the additional level of detail in MIDAS is really needed and whether a given version of MIDAS can be extended to cover a novel situation still needs to be determined." The authors identify this area as needing great attention in terms of advanced model development, modeling system safety with human/automation, model validations, and the integration of these models with other models.

Only two cost/benefit analyses were (then) found. ACIM was found to be an effective and mature tool for projecting growth and demand in both the airline and commercial aircraft industries.

6.3 ACATS

6.3.1 Barrer, J.N., P. Kuzminski, & W.J. Swedish (2005). Analyzing the Runway Capacity of Complex Airports. *Proceedings of the 5th Aviation, Technology, Integration, and Operations Conference*, Arlington, VA, pp. 1–7.

This paper includes descriptions of the Airport Capacity Analysis Through Simulation (ACATS) model developed by The MITRE Corporation. This paper describes the graphical user interface, the simulation module, and the methodology behind the algorithms of ACATS. "The user interface for ACATS provides a fast way to set up the elements of the airport that are essential for calculating runway capacity. It also supports the use of Air Traffic Control (ATC) separation rules that may become feasible as technology improves. The software in the user interface automatically converts the data for any airport into a standardized set of files that are then processed by the ACATS simulation software." "The output of ACATS includes an animation of the simulation, statistics about the observed throughput, and a set of graphical analysis charts. The animation and graphical results produced by ACATS are important tools in explaining the analysis to the end user and in validating the results of the simulation."

6.3.2 Barrer, J.N. (2006). *Airport Capacity Through Simulation (ACTS) Transition* [PDF PowerPoint slides]. Retrieved from http://www.mitre.org/news/events/tech06/briefings/1493.pdf.

This brief presentation highlights the need for a capacity analysis tool and provides screen shots of the ACATS graphical user interface and operations animation frame.

6.4 ACES

6.4.1 National Aeronautics and Space Administration (2004). *Airspace Concept Evaluation System* [PDF document]. Retrieved from http://vams.arc.nasa.gov/pubs/ACES_FactSheet_100704.pdf

This is a one page fact sheet about the Airspace Concepts Evaluation System (ACES), an agent based model and simulation environment developed at the NASA Ames Research Center. "This modeling approach isolates the individual models so they can continue to be enhanced, improved, and modified to represent new concepts with low development impact on the overall simulation system." It also lists various examples of ACES usage.

6.4.2 Sweet, D., V. Manikonda, J. Aronson, K. Roth, & M. Blake (2002). Fast-Time Simulation System for Analysis of Advanced Air Transportation Concepts. *Proceedings of the AIAA Modeling and Simulation Technologies Conference and Exhibit* (AIAA 2002-4593), Monterey, CA.

This is one of the earliest papers to present the ACES conceptual plan and discuss prototypes. The initial emphasis was to be on the development and validation of a toolbox of compatible models that can be configured to address many different concepts and evaluation criteria. The technologies for run-time communication between agents, data initialization and storage, and data access are presented. Additionally, lessons learned from prototype development are presented.

6.4.3 Couluris, G.J., C.G. Hunter, M. Blake, K. Roth, D. Sweet, P. Stassart, &A. Huang (2003). National Airspace System Simulation Capturing the Interactions of Air Traffic Management and Flight Trajectories. *Proceedings of the AIAA Guidance, Navigation, and Control Conference* (AIAA 2003–5597), Austin, TX.

The paper presents information about ACES and the underlying modeling concepts used. "The simulation accounts for terminal gate pushback and arrival, taxi, runway system takeoff and landing, local approach and departure, climb and descent transition, and cruise operations. ACES employs a multi-trajectory based modeling approach that currently models Traffic Flow Management, Air Traffic Control and Flight operations, en route winds, and airport operating conditions." "The ACES tool applies a continual feedback, hierarchical modeling process to capture actions and responses among scheduling and trajectory planning, flight deck trajectory management, Traffic Flow Management strategic trajectory planning, and Air Traffic Control tactical trajectory management operations. The intent is to quantitatively describe air traffic movement resulting from the interaction of the operational and technological constructs."

6.4.4 Zelinski, S., & T. Romer (2004). An Airspace Concept Evaluation System Characterization of National Airspace System Delay. *Proceedings of the 4th AIAA Aviation, Technology and Operations Conference* (AIAA 2004-6200), Chicago, IL.

The research highlighted in this paper utilizes the ACES simulation tool to establish an initial characterization of National Airspace System (NAS)–wide delay. It provides some details about the various ACES subroutines and their methodologies. ACES 1.2, which was used in this study, does not include sector capacity limits, separation constraints, flight plan rerouting, delays in the arrival terminal area and arrival surface, and en-route altitude and cruise speed changes. The paper also highlights options available in ACES 1.2, which are delay maneuvers and TRACON departure fix separation. "Delay maneuvers are lateral en route course alterations used to delay individual flights. The TRACON departure fix separation option provides a simulation of miles-in-trail separation of aircraft at each departure fix." The ACES tool models an airport's state per 15 minutes of run-time as either VFR or IFR, which in turn helps to define the airport's capacity.

6.4.5 Meyn, L.A., T.F. Romer, K. Roth, & L.J. Bjarke (2004). Preliminary Assessment of Future Operational Concepts Using the Airspace Concept Evaluation System. *Proceedings of the 4th AIAA Aviation, Technology and Operations Conference* (AIAA 2004-6508), Chicago, IL.

This paper also provides descriptions about ACES 1.2 and the various models within the ACES architecture. The agents in ACES assess projected demand over planning horizons, develop traffic flow plans, and issue traffic restrictions to other agents. The ATC agents within the simulation manage tactical flight movement by applying standard operating procedures subject to the traffic flow management (TFM) agent restrictions. The model allows four degrees of freedom to emulate the movement of each aircraft along a four-dimension trajectory in conformance with its current flight plan and clearance. The tool "treats the runway system node as the critical factor in modeling each terminal operation. In this modeling structure, each Airport TFM agent invokes its model to examine projected takeoff and landing traffic loading at the runway system based on the flight schedule."

6.4.6 Zelinski, S. (2005). Validating the Airspace Concept Evaluation System Using Real World Data. *Proceedings of the 5th AIAA Aviation, Technology and Operations Conference* (AIAA 2005-6491), San Francisco, CA.

This paper presents a case for environmental validity of the ACES tool using real-world historical flight operational data. The steps in preprocessing the input files are discussed. The inputs were select, actual single day's operations within the National Airspace System. The output indicated that the ACES produced delays and airport operational metrics were similar to the real world, with minor variations of delay by phase of flight. The paper also highlights the unintentional interaction between the generic nodal airport model and departure meter fix separation model within ACES. The paper does not mention which version/build was used in the validation.

6.4.7 Wieland. F. (2010). *Advanced NextGen Algorithm in ACES: DAC, CNS...* [PowerPoint Slides]. Retrieved from http://catsr.ite.gmu.edu/NASWideSim2/Wieland-ACESSystemWideModelingPresentation.pptx.

This presentation provides details about the ACES software architecture and the algorithms. The time required to simulate 1x traffic (nearly 50,000 flights) with a 3x4 quad 2.33 Hz Intel processor and 8GB memory is 90 minutes. Using the same hardware, the time required to complete a simulation for 3x traffic (nearly 150,000 flights) is 6 hours. The algorithms discussed in the presentation include voice/datalink models, message propagation, navigation, surveillance, and the automatic slicing algorithm for dynamic airspace units. The architecture for time-based merging and separation, separation assurance framework, and multi aircraft batch simulation tool also are presented. The latest version/build number is not presented.

6.5 ADSIM

6.5.1 Federal Aviation Administration (2010). *ADSIM (Airport Delay Simulation Model)*. Retrieved from http://www.tc.faa.gov/acb300/adsim.asp.

6.6 DELAYSIM

6.6.1 Flight Transportation Associates (2001). *DELAYSIM*. Retrieved from http://www.ftausa.com/delaysim.htm.

6.7 ENPRAS

6.7.1 **Flight Transportation Associates (2001). *ENPRAS*. Retrieved from http://www.ftausa.com/enpras.htm.**

6.8 FLAPS

6.8.1 **Flight Transportation Associates (2001). *FLAPS*. Retrieved from http://www.ftausa.com/flaps.htm.**

6.9 FTA Models

6.9.1 **Flight Transportation Associates (2001). *Modeling*. Retrieved from http://www.ftausa.com/ftamodel.htm.**

From the webpage, clicking on the internal link or scrolling down to the heading “FTA Analysis Tools and Models” leads to paragraph descriptions of DELAYSIM, FLAPS, TASIM, and TAXSIM. In addition to these tools, descriptions are included for the following:

6.9.1.1 DELAYS

6.9.1.2 GATESIM

6.9.1.3 RUNCAP

6.9.1.4 LANDSIDE

6.9.1.5 TOPSIM

6.9.1.6 GNPM

6.9.1.7 FLEETASSIGN

6.10 JSIMMOD

6.10.1 **AirportTools (2006). *AirportTools: Measuring Capacity Using JSIMMOD*. Retrieved from http://www.airporttools.com/jsimmod/Documentation/other/capacity/index.html.**

6.11 LMINET

6.11.1 **Long, D., V. Stouffer-Costonn, P. Kostiuk, R. Kula, & B. Fernandez (2001). *Integrating LMINET with TAAM and SIMMOD* (NASA Publication No. NASA/CR-2001-210875). Langley Research Center, Hampton, VA: National Aeronautics and Space Administration.**

This report highlights details of the LMINET model as well as integration issues. “LMINET is a queuing network model of the entire National Airspace System (NAS) developed by LMI for NASA” and “models flights among a set of airports by linking queuing network models of airports with sequences of queuing models of the Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC) sectors.” “LMINET can generate the average delay for all departures and arrivals during each epoch at each LMINET airport.”

6.11.2 **Long, D., & H. Hasan (2009). Improved Prediction of Flight Delays Using the LMINET2 System-Wide Simulation Model. *Proceedings of the 9th AIAA Aviation Technology, Integration, and Operations Conference*, Hilton Head, SC.**

6.12 NASPAC

6.12.1 Federal Aviation Administration (2010). *ACB-330/NASPAC*. Retrieved from http://www.tc.faa.gov/acb300/330_naspac.asp. At time of publication a functioning link to information about NASPAC was available at http://www.faa.gov/about/office_org/headquarters_offices/ang/offices/ac_td/at_sys_con_dev/sim_analysis_team/models/naspac/.

6.13 RAMS

6.13.1 ISA Software (2010). *RAMS Plus Simulation Solutions* [PDF document]. Retrieved from http://www.ramsplus.com/files/What%20Is%20RAMS%20Plus.pdf.

6.14 RDSIM

6.14.1 Federal Aviation Administration (2010). *RDSIM (Runway Delay Simulation Model)*. Retrieved from http://www.tc.faa.gov/acb300/rdsim.asp.

6.15 REDIM

6.15.1 Virginia Tech: Air Transportation Systems Laboratory (2010). *REDIM 2.0 User's Manual* [PDF document]. Retrieved from http://www.atsl.cee.vt.edu/Redim/Redim_2_Manual.pdf.

6.16 SIMMOD

6.16.1 Federal Aviation Administration (2010). *Simmod Manual: How Simmod Works* [PDF document]. Retrieved from http://www.tc.faa.gov/acb300/how_simmod_works.pdf.

6.17 SIMMOD PLUS

6.17.1 ATAC Corporation (2009). *ATAC Products & Tools: Simmod PLUS!* Information originally retrieved from http://www.atac.com/Products_Airports-b.html.

6.18 SIMMOD PRO

6.18.1 ATAC Corporation (2009). *ATAC Products & Tools: Simmod PRO!* Retrieved from http://www.atac.com/simmod-pro.html.

6.19 TAAM

6.19.1 Jeppesen (2010). *Jeppesen Total Airspace and Airport Modeler (TAAM)*. Retrieved from http://www.jeppesen.com/industry-solutions/aviation/government/total-airspace-airport-modeler.jsp;jsessionid=Lh2XDWnpgNPnH1BjrCvCfhpBNGhCRR6hX4g7s1C2ZJW8Sg26n6n0!-1409014597.

6.19.2 Preston Aviation Solutions Pty Ltd (2005). *TAAM 2.3 Reference Manual* (Document 11.001-06). Available from Preston Aviation Solutions Pty Ltd., Australia.

6.19.3 Boesel, J., C.X. Galdstone, J. Hoffman, P.A. Massimini, C. Shiotsuki, & B. Simmons (2001). *TAAM Best Practices Guidelines*. McLean, VA: The MITRE Corporation.

6.20 TASIM

6.20.1 Flight Transportation Associates (2001). TASIM. Retrieved from http://www.ftausa.com/tasim.htm.

6.21 TAXSIM

6.21.1 Flight Transportation Associates (2001). TAXSIM. Retrieved from http://www.ftausa.com/taxsim.htm.

6.22 The Airport Machine

6.22.1 Massachusetts Institute of Technology (1996). *The Airport Machine Review*. Retrieved from http://web.mit.edu/aeroastro/www/labs/AATT/reviews/airportmachine.html.

6.23 TSAM

6.23.1 Baik, H., & Trani, A.A. (2005). *A Transportation Systems Analysis Model (TSAM) to Study the Impact of the Small Aircraft Transportation System* (SATS) [PDF poster documentation]. Retrieved from http://www.atsl.cee.vt.edu/Publications/2005_A_Transportation_Systems_Analysis_Model_TSAM_to_study_the_impact_of_the_Small_Aircraft_Transportation_System_SATS.pdf.

6.24 VTASIM

6.24.1 Trani, A., & H. Baik (2002). VTASIM: A New Paradigm to Model Airport Operations. In: J. Rakas & S.A. Mumayiz (eds.). *Transportation Research E-Circular* (E-C042). Retrieved from TRB Publications Index.

6.25 Boeing Airport Capacity Constraints Model

7. Government and University Research Documents and Papers

7.1 Hockaday, S. & A.K. Kanafani (1974). Developments in Airport Capacity Analysis. *Transportation Research*, 8(3), 171–80.

This paper presents a model to calculate the runway capacity. The model assumes that the aircraft deviations (from intended paths) are normally distributed random variables. The model allows selection of strategies for actual and intended arrival-departure mix and also accounts for effects of wake turbulence. The model includes three mains steps. First, the time intervals between landing and departure operations are calculated. These intervals are then manipulated to produce capacity estimates using one (or combinations of) operating strategies, which include arrivals only, departures only, and mixed operations. Selection of the operating strategy that yields highest capacity is the final step.

7.2 Newell, G.F. (1979). Airport Capacity and Delays. *Transportation Science*, 13(3), 201–41.

This paper presents literature review of airport capacity. It highlights the dependence of airport capacity on types of operations, the runway geometry, and flight rules. Of particular interest are sections 5.a through 5.d, which discuss the airport capacity for various arrival/departure rates and its boundary curve for a single runway. The paper also discusses two and three parallel runway configurations.

7.3 Hansen, M., T. Nikoleris, D. Lovell, K. Vlachou & A Odoni (2009). Use of Queuing Models to Estimate Delay Savings from 4d Trajectory Precision. *Proceedings of the 8th U.S.A./Europe Air Traffic Management Research and Development Seminar*, Napa, CA.

The authors compare predicted values of delays using three queuing models across a range of demand and capacity scenarios at seven major U.S. airports. They estimate that simply better prediction of delays, without change in capacity, could reduce delays by 35% when the baseline delay is around 6 minutes. The difference in average delay predicted was found to be well-approximated as a constant on the order of 1 minute and a fraction of the stochastic delay on the order of 10%.

7.4 Mosquera-Benitez, D., A.R. Groskreutz, & L. Fucke (2009). Separation Minima Model. *Proceedings of the 8th U.S.A./Europe Air Traffic Management Research and Development Seminar*, Napa, CA.

This paper presents a tool to compare and understand the effect on separation minima. The study compiled 622 separation minima standards. They found only 15% of the cases listed contributing factors while 49% of the cases listed no factors. A model for calculating horizontal separation minima is developed.

7.5 Kim, A., & M. Hansen (2009). Validation of Runway Capacity Models. *Proceedings of the 8th U.S.A./Europe Air Traffic Management Research and Development Seminar*, Napa, CA.

This paper introduces two methodologies for validating capacity model results against empirical data. Their results indicate that the Airfield Capacity Model (ACM), developed by FAA and MITRE CAASD, and *runway*Simulator (rS), developed by MITRE CAASD, predict greater differences between average VMC and IMC capacity than do actual data. The models appeared to have over-predicted VMC capacities. Their results also indicate that the two models predicted wider ranges of capacities. Of the two models compared, the authors found rS model estimates to be better.

7.6 Trani, A.A. (2009). *Modeling and Simulation Tools for NextGen: A Few Missing Links* [PDF presentation slides]. Retrieved from http://www.nasug.com/200903/NASUG_VT_Spring2009.pdf.

This presentation highlights the gaps found in the simulation tools for NextGen. The focus is primarily on wake vortex simulation tools and 4D trajectories. It seems that this presentation is an outcome from the LMI report discussed previously (Item 6.1).

7.7 Klein, A., S. Kavoussi, & R.S. Lee (2009). Weather Forecast Accuracy: Study of Impact on Airport Capacity and Estimation of Avoidable Costs. *Proceedings of the 8th U.S.A./Europe Air Traffic Management Research and Development Seminar*, Napa, CA.

The authors present a model to quantify the impact of forecast weather on the NAS. The results of model-based arrival rates for 35 airports under a wide variety of weather conditions were compared against actual data and were found to be valid. The model can estimate the avoidable arrival delays attributable to terminal weather forecast, by specific weather factor. The authors estimate the annual cost of avoidable arrival delays related to terminal weather forecast is approximately $330M.

7.8 Jeddi, B., & J. Shortle (2007) Throughput, Risk, and Economic Optimality of Runway Landing Operations. *Proceedings of the 7th U.S.A./Europe Air Traffic Management Research and Development Seminar*, Barcelona, Spain, p. 162.

This paper proposes an optimization model to maximize successful landings on a single runway while mitigating wake-vortex encounter and simultaneous runway occupancy risks. “The risks are mitigated by enforcing go-around procedures when separation distances are too small." The authors also propose two tools. The first maximizes the risk-free throughput (number of successful landings per unit of time) with and without wake-vortex effects. The second maximizes expected net economic outcome (total dollar benefits minus total go-around costs) by adjusting the rate of landing attempts.

7.9 Shortle, J., & B. Jeddi (2007). Using Multilateration Data in Probabilistic Analysis of Wake Vortex Hazards for Landing Aircraft. *Transportation Research Record*, pp. 90–6.

A method to estimate wake alert probabilities based on a direct feed of flight-track data is provided. The model allows variation in atmospheric parameters to evaluate the potential range of wake alert probabilities. They found that under certain conditions a decrease in wake alert probability is not observed even if the wake can dissipate quickly. The wakes were found to remain for a longer period of time at a higher altitude before dissipating below a critical threshold. This effect becomes more pronounced with higher wake thresholds.

7.10 Byung, J.K., A. Trani, X. Gu, & C. Zhong (1996). Computer Simulation Model for Airplane Landing Performance Prediction. *Transportation Research Record*, 1562, pp. 53–62.

This paper presents a model to predict airplane landing performance on runways to locate high-speed exits. The landing process is considered to be of five parts: flare, first free roll, braking, second free roll, and turnoff. The authors found that the landing distance for a group of transport aircraft is probabilistic with a large dispersion. They also confirmed that runway length has a strong influence on the touchdown location in transport operations. The deceleration rates found their observational study indicated aircraft decelerate well below their maximum capabilities. The deceleration rate has a weak correlation with the flare (one of the five parts of the landing process) speed and the length of runway available for braking.

7.11 Zhang, Y., J. Rakas, & E. Liu (2006). Methodology for Estimating Airport Capacity and Throughput Performance Using PDARS. *Proceedings of the 10th Air Transport Research Society (ATRS) World Conference*, Nagoya, Japan.

This paper reports a method of assessing performance and proposes efficiency metrics for runway and airport utilization. The authors use normal-lognormal probability distribution for landing time intervals. They found that "each airport has a unique probability distribution for arrivals, depending on the number and complexity of runway layouts and runway configurations in use, weather conditions, traffic demand, aircraft mix, or air traffic control 'culture' deployed at an airport." A single-effect model with linear functions of major parameters (the target separation and the arrival rate) is proposed. The study confirmed that capacity variation occurs among different runway configurations.

7.12 Kumar, V., & L. Sherry (2008). *Airport Throughput Capacity Limits for Demand Management Planning* [PDF document]. Retrieved from http://catsr.ite.gmu.edu/pubs/ICNS_Kumar_Sherry.pdf.

This paper evaluates the variability of throughput capacity at the OEP-35 airports during the convective weather season in 2008. Thirteen airports showed a reduction of more than 20% in capacity more than 10% of the time. The paper helps establish the average costs of delays due to reduced capacity and the average profits per flight at each of the QEP-35 airports. Twenty-four airports exhibited an average cost of delays per flight in excess of the average profit generated by a flight. The authors also identify that the "optimum airport capacity, computed by trading-off flights delays and underutilization ranged from 81% to 100% of the maximum airport capacity. The average optimum airport capacity was 93% of the maximum airport capacity."

7.13 Gaier, E.M., & P.F. Kostiuk (1998). Evaluating the Economic Impact of ATM Innovations on Commercial Air Carrier Operations. *Proceedings of the 2nd U.S.A./Europe Air Traffic Management Research and Development Seminar*, Orlando, FL.

This paper discusses the Air Carrier Cost-Benefit Model (CBM), an analysis tool to support credible estimates of benefits to commercial airline operators from proposed technical and procedural innovations. This paper also analyzes the specific capacity-enhancement program Low Visibility Landing and Surface Operations (LVLASO), part of the NASA Terminal Area Productivity (TAP) Program. LVLASO seeks to augment existing airport capacity by reducing aircraft runway occupancy time, separation requirements, and taxi times in low visibility conditions. LVLASO is modeled using airport capacity and delay models and their results indicated modest benefits of LVLASO for commercial operators with substantial risk.

7.14 Jeddi, B., J. Shortle, L. Sherry (2006). Statistical Separation Standards for the Aircraft-Approach Process. *Proceedings of the 25th Digital Avionics Systems Conference* (2A1-1–2A1-13).

7.15 Levy, B., J. Legg, and M. Romano (2004). Opportunities for Improvements in Simple Models for Estimating Runway Capacity. Presented at the *23rd Digital Avionics Systems Conference,* Salt Lake City, UT.

7.16 Lee, D.D., A. Smith, R. Cassell, & B. Abdul-Baki (1999). NASA Low Visibility Landing and Surface Operations (LVASO) Runway Occupancy Time (ROT) Analysis, IEEE 0-7803-5749-3/99.

7.17 Wieland, F. (2006). Investigating the Volume-Delay Relationship at Congested Airports. *Proceedings of the 6th AIAA Aviation, Technology and Operations Conference* (AIAA 2006-7747), Wichita, KS.

7.18 Andrews, J., & J.E. Robinson (2001). Radar-based Analysis of Efficient Runway Use. *Proceedings of the AIAA Guidance, Navigation and Control Conference*, Montreal, Quebec.

7.19 MIT Lincoln Laboratory (1993). *Evaluation of the Capacity and Delay Benefits of Terminal Air Traffic Control Automation* (Report ATC-192). Lexington, MA: S.B. Boswell

DATA SOURCES

This section lists sources of information about each of the factors that influence capacity estimates. Additionally, more detailed descriptions are included for sources for track data, aircraft counts, and runway occupancy time.

Runway Exit Design, Runway Entrance Taxiways, Departure Staging and Sequencing of Taxiways or Areas, Runway Crossings, Parallel Taxiway

Data Requirements	Description
1. Sources	FAA airport diagrams Google maps of airports
2. Availability	Publicly available
3. Type	Scaled maps and images
4. Format	Electronic and paper
5. Age	Recent
6. Volume	N/A
7. Cost	No cost
8. Post-processing	N/A
9. Limitations	N/A
10. Default values	N/A

Airline Fleet Mix, Airline Scheduling Practices

Data Requirements	Description
1. Sources	BTS—AOTP database FAA—ASQP/ASPM database
2. Availability	BTS—AOTP database (publicly available) FAA—ASQP/ASPM database (credible entities may apply to FAA for access to the database)
3. Type	Historical data, tables
4. Format	Electronic
5. Age	Period/season under investigation
6. Volume	Week or month
7. Cost	No cost
8. Post-processing	None
9. Limitations	N/A
10. Default values	N/A

Aircraft Avionics Equipage

Data Requirements	Description
1. Sources	Forecast equipage profiles for fleets (aircraft manufacturers order lists, FAA, Mitre CAASD)
2. Availability	Publicly available
3. Type	Historical data and forecast data
4. Format	Electronic, paper
5. Age	N/A
6. Volume	N/A
7. Cost	N/A
8. Post-processing	None
9. Limitations	N/A
10. Default values	N/A

Aircraft Performance Random Variability, Human Factors Random Variability

Data Requirements	Description
1. Sources	TRACON/surface track data
2. Availability	FAA-funded equipment, then FAA proprietary Airport- or airline-funded equipment, then available from source
3. Type	Historical data (requires post-processing)
4. Format	Electronic
5. Age	N/A (Note: important to cover all runway/arrival fix/departure fix configurations)
6. Volume	Approaches and departures for each runway
7. Cost	N/A
8. Post-processing	Track data must be processed to estimate impact
9. Limitations	N/A
10. Default values	10 seconds ATC buffer

Visual Flight Rules and Visual Approaches	
Data Requirements	**Description**
1. Sources	Charts— – Standard Terminal Arrivals (STARS), Instrument Approach Procedures (IAP), Departure Procedures (DP).
2. Availability	FAA (alternative sources: airnav.com, skyvector.com)
3. Type	Aeronautic charts
4. Format	Electronic or paper
5. Age	Check for latest/planned revision
6. Volume	N/A
7. Cost	No cost
8. Post-processing	None
9. Limitations	N/A
10. Default values	N/A

Weather	
Data Requirements	**Description**
1. Sources	FAA—ASPM database FAA—TAF database
2. Availability	FAA—ASPM database (credible entities may apply to FAA for access to the database) FAA—TAF database
3. Type	Historical data, tables,
4. Format	Electronic
5. Age	Period/season under investigation
6. Volume	Week or month
7. Cost	No cost
8. Post-processing	None
9. Limitations	N/A
10. Default values	N/A

Wake Turbulence

Data Requirements	**Description**
1. Sources	U.S. Department of Transportation, Federal Aviation Administration Air Traffic Organizational Policy JO 7110.65U
2. Availability	Publicly available http://www.faa.gov/documentLibrary/media/Order/ATC.pdf
3. Type	Regulations
4. Format	Electronic
5. Age	Most recent
6. Volume	N/A
7. Cost	No cost
8. Post-processing	None
9. Limitations	N/A
10. Default values	N/A

Multiple Approach Technology

Data Requirements	**Description**
1. Sources	TRACON/surface track data
2. Availability	FAA-funded equipment, then FAA proprietary Airport- or airline-funded equipment, then available from source
3. Type	Historical data (requires post-processing)
4. Format	Electronic
5. Age	N/A (Note: important to cover all runway/arrival fix/departure fix configurations)
6. Volume	Multiple approach
7. Cost	N/A
8. Post-processing	Track data must be processed to estimate impact
9. Limitations	N/A
10. Default values	Excess distance flown, runway throughput

Human Factors (Controller Workload), Human Factors (Air-Ground Communications)

Default values: 8 seconds to 30 seconds, depending on traffic count and complexity of communication.

Neighboring Airports (STARs, Approaches and SIDS)—Used in Conjunction with Published Procedures

Data Requirements	Description
1. Sources	
2. Availability	Publicly available
3. Type	Standards
4. Format	Electronic navigation database and paper
5. Age	Latest revisions
6. Volume	N/A
7. Cost	Nominal fee
8. Post-processing	Analysis required to overall the procedures and see intersections
9. Limitations	This analysis will show the published procedure intersections. Must use track data to see deviations from procedures.
10. Default values	N/A

Departure Fix Restrictions—Derived from Throughput at Fixes from Track Data

Data Requirements	Description
1. Sources	TRACON/surface track data
2. Availability	FAA-funded equipment, then FAA proprietary Airport- or airline-funded equipment, then available from source
3. Type	Historical data (requires post-processing)
4. Format	Electronic
5. Age	N/A (Note: important to cover all runway/arrival fix/departure fix configurations)
6. Volume	Multiple runway/arrival fix/departure fix configurations
7. Cost	N/A
8. Post-processing	Track data must be processed to estimate departure fix throughputs
9. Limitations	N/A
10. Default values	Count of flights per 15 minutes at each fix for each runway/arrival fix/departure fix configurations

Neighboring Airports (Radar Track Data)—Used in Conjunction with Published Procedures

Data Requirements	Description
1. Sources	TRACON/surface track data.
2. Availability	FAA-funded equipment, then FAA proprietary Airport- or airline-funded equipment, then available from source
3. Type	Historical data (requires post-processing)
4. Format	Electronic
5. Age	Check navigation charts for revision dates (older data may no longer be relevant) (Note: important to cover all runway/arrival fix/departure fix configurations)
6. Volume	Multiple runway/arrival fix/departure fix configurations
7. Cost	N/A
8. Post-processing	Track data must be processed to identify intersecting trajectories
9. Limitations	N/A
10. Default values	Count of intersecting trajectories

Missed Approach and Balked Landing Procedures

Data Requirements	Description
1. Sources	TRACON/surface track data Air navigation charts
2. Availability	FAA radar data collected on FAA-funded equipment (therefore FAA proprietary) Airport- or airline-funded equipment, then available from source (FAA will limit access to data based on national security requirements)
3. Type	Historical data (requires post-processing)
4. Format	Electronic
5. Age	N/A (but if charted procedures have changed, older data may not be relevant) (Note: important to cover all runway/arrival fix/departure fix configurations)
6. Volume	Multiple runway/arrival fix/departure fix configurations (need multiple days on each configuration to capture a significant volume of missed approach data)
7. Cost	N/A
8. Post-processing	Track data must be processed to count go-arounds
9. Limitations	N/A
10. Default values	Count of missed approaches less than five per day at major airports

Track Data

This section describes the two sources of track data available in the United States: Perfor
Analysis and Reporting System (PDARS) and Airport Surface Detection, Model X (ASDE-X)

Performance Data Analysis and Reporting System

PDARS data and measurements are based on the processing of radar track and flight plai from Automatic Radar Terminal System (ARTS) computers at the TRACONs, and data coll host computers at the ARTCCs. These data provide more details of tracks flown than the Traffic Management System (ETMS) or its commercial ASD Feed (used in the industry).

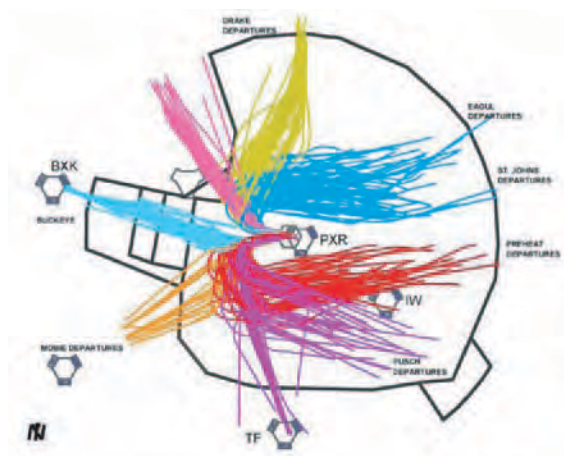


Figure B-1. Departure tracks for departures from Phoenix-Sky Harbor Runways (den Braven & Schade, 2003).

The types of information generated from PDARS data include:

- Travel times within geometric areas (sectors, facilities, etc.)
- Travel times for routing segments (arrival fix to runway, runway to departure fi boundary to/from runway, etc.)
- Flow counts over user-defined points
- Throughput counts for airports, sectors, etc.
- Groundspeed distributions at user-defined times and areas
- Identification of aircraft deviating from a prescribed procedure

PDARS data can be used to identify and generate statistics for events, such as sector crossings, as seen in Figure B-2.

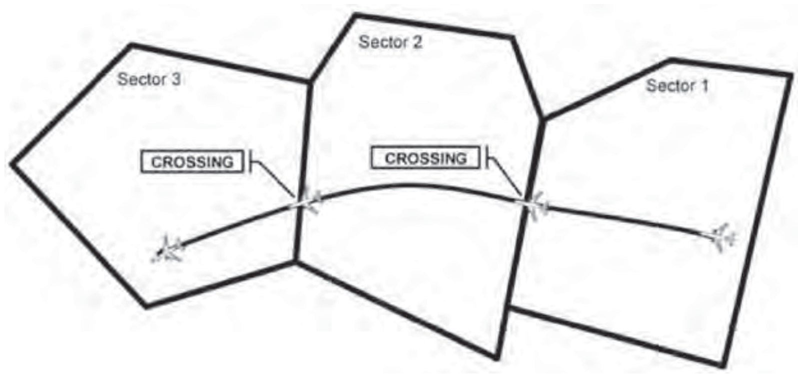


Figure B-2. Sector crossings.

PDARS data are available from the following facilities:

Western Pacific Region:

- Oakland Center (ZOA)
- Los Angeles Center (ZLA)
- Northern California TRACON (NCT)
- Southern California TRACON (SCT)
- Phoenix TRACON (P50)
- Western Pacific Regional Office (AWP)

Southwest Region:

- Albuquerque Center (ZAB)
- Houston Center (ZHU)
- Fort Worth Center (ZFW)
- Dallas/Fort Worth TRACON (D10)
- Houston TRACON (I90)
- Southwest Regional Office (ASW)

Southern Region:

- Jacksonville Center (ZJX)
- Memphis Center (ZME)
- Atlanta Center (ZTL)
- Miami Center (ZMA)

Great Lakes Region:

- Indianapolis (ZID)

National:

- ATC System Command Center (ATCSCC) in Herndon, Virginia

Format

A sample format of PDARS data is shown below.

1,BFF,2.6

5,ATAC Corporation,BirdWatch Analysis Module,4.5.5

0,

2(Record Type),1205894410.240(Time),52533(Flight ID),2723(Beacon Code),721(Unknown),0/JFK(Original Airport),,CAL011(Aircraft ID),1,B744(Aircraft Type),JFK(Original Airport),GAY(Destination Airport),D(Operation Type),JFK,?

4,1205894410.240,52533,2723,721,0/JFK,1353,CAL011,1,B744,JFK,GAY,N,-99.00,-99.00,340,,?,-00099,I,J,D,?,-099,?,5,,,,,,

4,1205901708.450,52533,2723,721,3/HPN,1353,CAL011,1,B744,JFK,GAY,N,-99.00,-99.00,340,,?,-00099,I,J,D,?,-099,?,5,,,,,,

3(Record Type),1205901651.730(Time),52533(Flight ID),2723(Beacon Code),721(Unknown),0/JFK(Original Airport),1350,CAL011(Aircraft ID),1,40.63518(Latitude),-73.78761(Longitude),4.76(Altitude *100),1,0.003,0.003,-99.00,153(Speed),104,2004,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901660.714,52533,2723,721,0/JFK,1350,CAL011,1,40.63221,-73.78042,7.76,3,0.002,0.002,-99.00,153,104,2004,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901669.583,52533,2723,721,0/JFK,1350,CAL011,1,40.62907,-73.77326,9.85,1,0.002,0.002,-99.00,158,106,1807,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901673.996,52533,2723,721,0/JFK,1350,CAL011,1,40.62801,-73.76911,10.76,2,0.002,0.002,-99.00,166,94,1237,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901678.408,52533,2723,721,0/JFK,1350,CAL011,1,40.62786,-73.76476,12.76,4,0.002,0.002,-99.00,166,78,1593,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901682.838,52533,2723,721,0/JFK,1350,CAL011,1,40.62761,-73.76026,13.76,10,0.002,0.002,-99.00,168,80,1564,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901691.794,52533,2723,721,0/JFK,1350,CAL011,1,40.62745,-73.75134,16.76,1,0.003,0.003,-99.00,171,77,1564,?,?,?,-99,,-99,,,,,,0,48,0,?,2,A,JFK

3,1205901696.315,52533,2723,721,0/JFK,1350,CAL011,1,40.62742,-73.74665,17.76,9,0.004,0.004,-99.00,173,76,1332,?,?,?,-99,,-99,,,,,,48,50,2,K,130,D,JFK

3,1205901700.860,52533,2723,721,0/JFK,1350,CAL011,1,40.62749,-73.74191,17.76,9,0.004,0.004,-99.00,176,75,1318,?,?,?,-99,,-99,,,,,,48,50,2,K,130,D,JFK

3,1205901705.420,52533,2723,721,0/JFK,1350,CAL011,1,40.62751,-73.73702,18.76,5,0.005,0.005,-99.00,177,75,1310,?,?,?,-99,,-99,,,,,,48,56,2,K,130,D,JFK

Record-type = 2 denotes a flight-header record in PDARS

Record-type = 3 denotes a position record

Airport Surface Detection, Model X

ASDE-X data provides track and identification data for aircraft and equipped vehicles on the airport's surface as well as aircraft within approximately 5 miles of the airport.

The core ASDE-X track data includes a radar sensor and a multilateration sensor capable of receiving Automatic Dependent Surveillance—Broadcast (ADS-B) from the aircraft. The ASDE-X Multiprocessor subsystem combines independent surveillance data from the radar subsystem with cooperative and dependent data from the multilateration subsystem to provide a single target with Flight ID for display to air traffic control. The multiprocessor subsystem may also integrate data from Automated Radar Terminal System (ARTS) and the Standard Terminal Automation Replacement System (STARS) as well as the Airport Surveillance Radar (ASR), dependent on the implementation chosen for a given site. The system is capable of using all sensors at once, or using each sensor alone.

The 35 airports scheduled to have ASDE-X installation are listed below. Airports with ASDE-X operating as of July 2010 are shown with an asterisk.

- Baltimore-Washington International Thurgood Marshall Airport (Baltimore, MD)
- Boston Logan International Airport (Boston, MA)*
- Bradley International Airport (Windsor Locks, CT)*
- Chicago Midway Airport (Chicago, IL)*
- Chicago O'Hare International Airport (Chicago, IL)*
- Charlotte Douglas International Airport (Charlotte, NC)*
- Dallas-Ft. Worth International Airport (Dallas, TX)*
- Denver International Airport (Denver, CO)*
- Detroit Metro Wayne County Airport (Detroit, MI)*
- Ft. Lauderdale/Hollywood Airport (Ft. Lauderdale, FL)*
- General Mitchell International Airport (Milwaukee, WI)*
- George Bush Intercontinental Airport (Houston, TX)*
- Hartsfield-Jackson Atlanta International Airport (Atlanta, GA)*
- Honolulu International –Hickam Air Force Base Airport (Honolulu, HI)*
- John F. Kennedy International Airport (Jamaica, NY)*
- John Wayne-Orange County Airport (Santa Ana, CA)*
- LaGuardia Airport, (Flushing, NY)
- Lambert-St. Louis International Airport (St. Louis, MO)*
- Las Vegas McCarran International Airport (Las Vegas, NV)
- Los Angeles International Airport (Los Angeles, CA)*
- Louisville International Airport-Standiford Field (Louisville, KY)*
- Memphis International Airport (Memphis, TN)

- Miami International Airport (Miami, FL)*
- Minneapolis St. Paul International Airport (Minneapolis, MN)*
- Newark International Airport (Newark, NJ)*
- Orlando International Airport (Orlando, FL)*
- Philadelphia International Airport (Philadelphia, PA)*
- Phoenix Sky Harbor International Airport (Phoenix, AZ)*
- Ronald Reagan Washington National Airport (Washington, DC)
- San Diego International Airport (San Diego, CA)*
- Salt Lake City International Airport (Salt Lake City, UT)*
- Seattle-Tacoma International Airport (Seattle, WA)*
- Theodore Francis Green State Airport (Providence, RI)*
- Washington Dulles International Airport (Chantilly, VA)*
- William P. Hobby Airport (Houston, TX)*

Format

A sample format from an ASDE-X system is shown below.

HR	MIN	SEC	X	Y	Height	ACID	AcType
09	59	21.000	6833	-16909	8068.75	DAL104	B764
09	59	22.000	6724	-16836	8056.25	DAL104	B764
09	59	23.000	6614	-16763	8037.5	DAL104	B764
09	59	24.000	6505	-16691	8018.75	DAL104	B764
09	59	25.000	6396	-16618	8000.0	DAL104	B764
09	59	26.000	6300	-16533	7856.25	DAL104	B764
09	59	27.000	6192	-16459	7818.75	DAL104	B764
09	59	28.000	6085	-16385	7787.5	DAL104	B764
09	59	29.000	5977	-16311	7750.0	DAL104	B764
09	59	30.000	5861	-16258	7662.5	DAL104	B764
09	59	31.000	5752	-16186	7625.0	DAL104	B764
09	59	32.000	5644	-16114	7593.75	DAL104	B764

Msg_Type Time ACID TrackNum AcType Lat/Long/Altitude

DD_TRACK 1183335341631 - 29 11152295 -1 - - N/A 325348.1198605895/970159.4251284003/575.0 677/-17 0.0 6.0 false -1 - 1183335342000 1009132

DD_TRACK 1183335341631 AAL1871 243 10595333 -1 - - MD82 325305.30234992504/970305.1284533739/975.0 -1031/-1336 -9.721148 -92.49054 false -1 - 1183335342000 1008970

DD_TRACK 1183335341631 - 213 9015376 -1 - - N/A 325350.6506253779/970333.3443534374/-1.0 -1764/61 0.0 0.0 false -1 - 1183335342000 0

DD_TRACK 1183335341631 FW1 205 1 -1 - - HELO 324203.5883772373/971531.2270015478/1300.0 -20468/-21701 1.4657788 41.974415 false -1 - 1183335342000 0

DD_TRACK 1183335341631 UNKN 207 11025938 -1 - - N/A 325326.27447515726/970203.4371766448/-1.0 572/-690 0.0 0.0 false -1 - 1183335342000 0

DD_TRACK 1183335341632 EGF670 244 1 -1 - - E135 324420.83295568824/971052.6947163045/11000.0 -13213/-17493 94.95285 91.69491 false -1 - 1183335342000 1009119

DD_TRACK 1183335341632 N88XJ 134 1 -1 - - BE9L 325204.63490590453/964530.7500444353/3000.0 26384/-3170 -95.03762 71.61599 false -1 - 1183335342000 0

DD_TRACK 1183335341632 EGF849 208 11207505 -1 - - E135 325416.91089332104/970248.739888072/-1.0 -605/870 -0.0 -0.0 false -1 - 1183335342000 1009101

Aircraft Count Data

Three sources of aircraft count data are Aviation System Performance Metrics (ASPM), Official Airline Guide (OAG), and Enhanced Traffic Management System Counts (ETMSC). These three databases are described below.

Aviation System Performance Metrics

The Aviation System Performance Metrics (ASPM) provides data on IFR flights to and/or from major airports (approx 77) and on all flights by specified carriers (approx 22). Flights include international and domestic airports. The ASPM data includes:

- Airport weather (VMC, MVMC, IMC)
- Runway configuration
- Arrival rates
- Departure rates

OAG

OAG Flight Guide (the OAG) is the complete printed reference on worldwide flight schedules. The OAG is updated monthly and lists full details of direct and connecting flights, transfer times, and flight routings. It is the only publication to cover global flight listings. The OAG also includes a wealth of supplementary information, including industry codes, equipment types, and contact details for the world's airlines and airports.

Enhanced Traffic Management System Counts

The Enhanced Traffic Management System Counts (ETMSC) is designed to provide information on traffic counts by airport or by city pair for various data groupings (such as aircraft type or by hour of the day). Information on oceanic flights, fractional ownership flights, or business jet activity is also maintained. ETMSC source data are derived from filed flight plans and/or when flights are detected by the National Airspace System (NAS), usually via radar. ETMSC records are assembled by FAA's Air Traffic Airspace (ATA) Lab by combining electronic messages transmitted to the host (en route) computer for each flight into a complete record of that flight. ETMSC has three views: Airport, City Pair, and Distributed OPSNET. It includes information about commercial traffic (air carriers and air taxis), general aviation traffic, and military air traffic to and from every landing facility, as well as fixes, both in the United States and in nearby countries that participate in the ETMS system. Data for each month are made available to the

ETMSC data access system approximately 10 days after the end of the month. Preliminary next-day ETMS data and enhanced 5-day data are used to construct ASPM records, but these preliminary data are not reported in the ETMSC data access system.

Arrival and Departure Runway Occupancy Times

7.1) Definition

Runway Occupancy Time (ROT) is a statistical distribution of the time aircraft occupy the runway. The time starts when the aircraft crosses the runway threshold and ends when the aircraft has cleared the runway (by more than x distance).

Arrival runway occupancy time (AROT) begins when an arriving aircraft passes over the runway threshold and ends when it exits the runway. Without an available parallel taxiway, AROT includes time for the aircraft to taxi to the end of the runway, turn around, and taxi back on the runway until it reaches one of the centrally located taxiways leading to the aircraft parking ramp. Departure runway occupancy time (DROT) begins when a departing aircraft begins to taxi to the end of the runway and includes the time it takes for the aircraft to turn around, complete its takeoff roll along the runway, and clear the opposite end of the runway.

The starting and ending locations for measuring ROT are shown in Figure B-3 by the X at time t_0 and the X at time t_1.

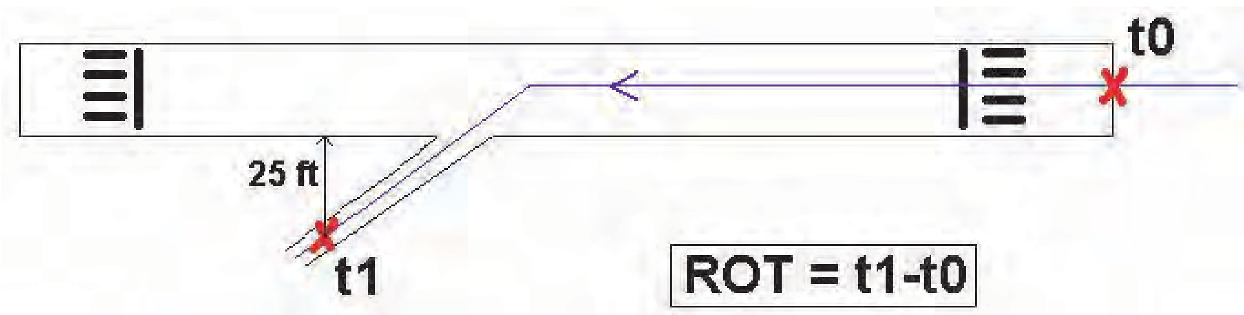


Figure B-3. Boundaries Used for Estimation of ROT.

ROT data typically appears in the form of a normal distribution (e.g., a bell-curve with mean = 45 seconds and standard deviation = 8 seconds).

The ROT distribution is determined by fleet mix (i.e., landing speed), runway layout (e.g., high speed exits), and taxi instructions and airports surface flow (e.g., relative location of gates).

7.2) Data Used

PDARS, ASDE-X

7.3) Data Analysis Process

Deriving the ROT distribution from surface track data requires a four-step process:

Step 1: Identify arrival tracks. The first step in the process is to parse the surface data to identify tracks associated with arrivals.

One approach is to sort the list of tracks by time of day. Then use the first set of track points to estimate the initial velocity. Tracks with a velocity greater than a threshold (e.g., 80 knots) can reliably be identified as arrivals. Tracks with a velocity equal to or less than 80 knots at the threshold can be identified reliably as departures. This relationship can be expressed as:

If (VelocityTrackStart > 80 knots) then {Operation = Arrival}

Else {Operation = Departure}

Step 2: Identify runway for each track. The nature of arrival operations is that they pass directly over the runway threshold. This fact can be used to identify which runway is being used.

One approach is to examine the track data relative to polygons that identify each runway threshold. Another less processing-intensive approach is to examine the first batch of hits (e.g., n = 80) in each track of the tracks tagged as arrival tracks and compute the minimum ground track distance (i.e., x and y, but no z) between each hit and each runway threshold. The runway used by the track is the arg min d_i, where d_i is the distance to each runway threshold i.

Step 3: Compute ROT for each track. ROT for a flight is defined as ROT = t_1 - t_0, where t_0 is the time the track crosses the runway threshold, and time t_1 is the time the aircraft has exited the runway by more than x distance (e.g., 25 feet).

One fast algorithm to determine when the aircraft track enters and then exits the polygon defining the runway boundary is to use a point-in-a-polygon method. This approach can be summarized as follows: Compare each side of the polygon to the Y (vertical) coordinate of the test point. Compile a list of **nodes,** where each node is a point where one side crosses the Y threshold of the test point. If there are an *odd* number of nodes on each side of the test point, then it is inside the polygon; if there are an *even* number of nodes on each side of the test point, then it is outside the polygon.

Step 4: Collate ROT for ROT Distribution. A histogram can be created based on the ROT for each track for each runway. Histograms can also be created for each aircraft class or for each type of runway usage (e.g., high speed exit). An example histogram for ROT is shown in Figure B-4.

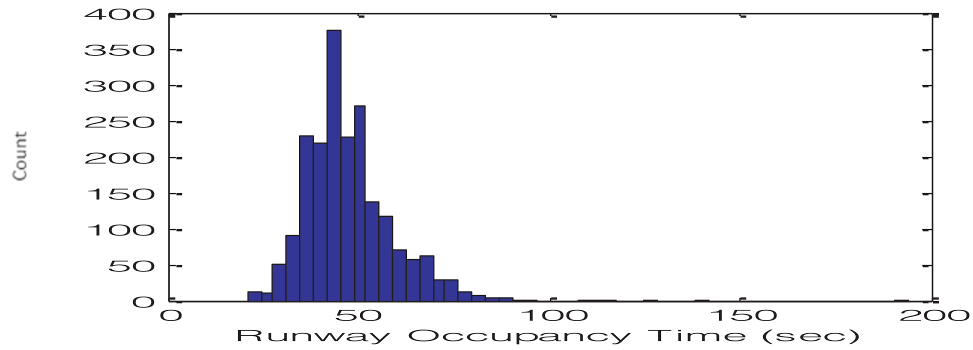


Figure B-4. Example histogram for ROT.

The best fit probability density function (pdf) for ROT is generally an Erlang distribution (e.g., 20.5 + Erlang[4.51,6]). When outliers are removed from the data, a normal pdf provides the best fit (e.g., mean = 47.5, sigma = 11).

Table B-1 shows an example of ROT by aircraft type. Table B-2 shows an example of ROT by runway used.

Table B-1. Example ROT by aircraft type.

Category	Count	Minimum	Maximum	Median	Mean	Standard Deviation
Small	104	22	115	45	47.6	15.1
Large	1710	21	194	46	47.3	11.6
B757	140	24	82	48	48.5	9.5
Heavy	81	29	92	53	56.4	15.8

Table B-2. Example ROT by aircraft type.

Runway	Count	Minimum	Maximum	Median	Mean	Standard Deviation
18L/36R	21	30	76	52	51.4	9.5
18R/36L	765	22	92	42	43.4	9.1
17R/35L	29	40	139	54	58.2	18.3
17C/35C	859	28	194	48	48.6	10.7
17L/35R	27	32	76	47	50.1	10.2
13L/31R	1	59	59	59	59	0
13R/31L	333	21	115	54	54.4	16

Abbreviations and acronyms used without definitions in TRB publications:

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