ACRP 03-17
EVALUATING AIRFIELD CAPACITY

Contractor's Final Report

Prepared for
Airport Cooperative Research Program
Transportation Research Board
of
The National Academies

LeighFisher

in association with

Landrum & Brown

Wilbur Smith Associates

George Mason University

University of California, Berkeley

and

Presentation & Design, Inc.

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Project No. ACRP 03-17

CRP STAFF FOR ACRP REPORT

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Mr. Joseph J. Brown-Snell, Transportation Research Board

Interested Observers

Mr. Kent Duffy, Federal Aviation Administration
Mr. Donald Guffey, Federal Aviation Administration

AUTHOR ACKNOWLEDGEMENTS

The research discussed in this report was performed under ACRP Project 03-17, "Evaluating Airfield Capacity," by a research team of recognized experts in airport planning, air traffic control and airfield operations, and airfield and airspace capacity. LeighFisher was the primary research consultant. William J. Dunlay, PhD, Director at LeighFisher was the Principal Investigator; and Suzanne E. Akkoush, Senior Consultant at LeighFisher, was the project manager. Landrum & Brown was the Principal Subconsultant for the research. Matthew H. Lee, Vice President at Landrum & Brown, was the Deputy Principal Investigator; and Pamela S. Keidel-Adams, managing director at Landrum & Brown, was the deputy project manager. The other authors were Brian R. Poe, Consultant at Landrum & Brown; Mark Hansen, professor at the University of California, Berkeley; Lance Sherry, Associate Professor (Research) at the George Mason University; and Yi Liu, PhD student at the University of California, Berkeley. Patti Douglas, President at Presentation & Design Inc., provided graphical support throughout the research process. The research team would like to express its gratitude to the members of the ACRP 03-17 Project Panel for their support and insightful comments during periodic document reviews. The research team would also like to thank the many aviation researchers and airport staff who took the time to share their insights, experience, and opinions with the research team; in particular, the staff at MITRE Corporation for their cooperation and for providing a testing license for the *runway*Simulator and Jim Henriksen of Wolverine software for providing a runtime license for SLX and Proof.

ABSTRACT

This Report documents research sponsored by the Airport Cooperative Research Program intended to present techniques, methods, and models that can be used to evaluate airfield capacity at a wide range of airports, and also to address the specific factors that affect airfield capacity. The main objective of this research was to create a Guidebook to (1) describe and assess relevant methods and modeling techniques for evaluating existing and future capacity for airports, (2) provide guidance on selecting the appropriate capacity analysis method, (3) provide best practices in assessing airfield capacity and applying the modeling techniques, and (4) outline specifications for new models, tools, and enhancements. The Guidebook includes background on airfield components and operations, description of existing modeling tools and their appropriate uses and limitations, and explanation of new modeling tools created as part of the research, and a decision tool to help select a capacity evaluation technique. This Final Report includes description of existing models and gap analysis, a selection of capacity analysis case studies, and technical outcomes of a model validation effort.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This Report documents research sponsored by the Airport Cooperative Research Program intended to present techniques, methods, and models that can be used to evaluate airfield capacity at a wide range of airports, and also to address the specific factors that affect airfield capacity. The Guidebook includes background on airfield components and operations, description of existing modeling tools, their appropriate uses, and limitations, explanation of new modeling tools created as part of the research, and a decision tool to help select a capacity evaluation technique. This Final Report includes a summary of the research as well as four technical appendices:

- Appendix 1: Airfield Capacity Case Studies
- Appendix 2: Review of Available Models
- Appendix 3: ACRP Capacity Spreadsheet Model Validation
- Appendix 4: *runway*Simulator Testing and Validation

A main outcome of this research is a prototype model, called the ACRP Capacity Spreadsheet Model. Outcomes of the validation effort of this tool can be found in Appendix 4 of the Final Report, and a user's manual for the tool can be found in Appendix A of the Guidebook.

OBJECTIVES

The objective of this research is to develop a guidebook to assist airport planners with airfield and airspace capacity evaluation. The guidebook will address airport airfield and airspace capacity planning at all types of airports. The term "airfield" capacity refers to runways, taxiways, apron areas, and aircraft parking positions. "Airspace" capacity for this research is defined as the approach and departure procedures in the immediate vicinity of an airport that directly affects airfield capacity. The guidebook (1) includes an assessment of relevant methods and modeling techniques for evaluating existing and future capacity for airports beyond those outlined in the current the FAA's Advisory Circular 150/5060-5 Airport Capacity and Delay (Advisory Circular) or the Airport Capacity Model; (2) identifies the limitations of the existing techniques; and (3) develops specifications for new models, tools, or enhancements. This guidebook will present capacity modeling guidelines that will improve the decision-making process for determining the appropriate level of modeling sophistication for a given planning study or capital improvement project and make the process more consistent from airport to airport. A functional prototype of one or more modeling tools will also be developed as part of this project.

APPROACH

The work was conducted in six major steps described below.

1. *Collect Existing Pertinent Research*. This task entailed an inventory of literature and research on capacity analysis, supplemented by the Team's professional experience, documenting the following:

    a. Airport case studies showing the range of capacity issues addressed by FAA, airports, and their consultants;

    b. The range of issues and factors which determine airport capacity;

    c. Research libraries of existing and on-going research on airport capacity issues, resulting in an annotated bibliography;

    The documentation of this Task was submitted as part of the Interim Report, and is included in the appendices to this Report and/or the Guidebook.

2. ***Identify/Describe Data Requirements.*** This Task identified types and sources of data, defined the levels of modeling sophistication, and summarized factors affecting the choice of modeling sophistication level. This Task included the following steps:

    a. Identify and describe data requirements typically needed for various capacity analyses and key sources currently available for such data

    b. Identify and describe the types of projects for which capacity analyses are required or otherwise applicable, and recommend the modeling sophistication level for each type of project

    c. Summarize the factors that affect the choice of modeling sophistication level for a particular application requiring airfield capacity information

    This Task was documented in the Interim Report, and can now be found in the Guidebook and Final Report.

3. ***Gap Analysis***. This Task identified limitations in the currently available modeling techniques and recommendations for improvement, through the following steps:

    a. Levels of modeling sophistication identified in Task 2 were examined for operational constraints, scalability, cost effectiveness, data requirements, taxiway configurations, variability, and other considerations.

    b. Summarized identified gaps at each level of modeling sophistication

This Task was documented in the Interim Report, and can now be found in the Guidebook and Final Report.

4. ***Prioritize/Recommend Enhancements.*** Based on the findings of the gap analysis from Task 3, functional enhancements and improvements for the various levels of modeling sophistication were prioritized according to importance.

   a. Estimated the level of effort and resources to address the identified gaps

   b. Prioritize candidate model enhancements based on possibility of accomplishing the enhancement within the schedule and budget, and relative importance

   In collaboration with the Panel, selected model enhancements for all levels except Level 5.

5. ***Prepare Model Development Plan/Testing Regime.*** In this Task, a prototype tool was developed in accordance with the findings of Task 4. In addition, a testing regime was executed on this new tool and a newly available capacity analysis tool.

   a. Designed model interface and software architectural design

   b. Built functional model prototype

   c. Tested model's functional capability

6. ***Develop the Guidebook*.** The results of Steps 1 through 5, as well as the collective professional experience of the research team, were combined to create the Guidebook. The Guidebook's main chapters document the background issues, existing models, new and newly available models, how to select a modeling tool, and subsequent uses of capacity estimates. Detailed technical descriptions and is provided in the appendices.

FINDINGS AND RESULTS

This research identified two main gaps in reviewing existing capacity modeling tools, leading to two main recommendations for model enhancement:

1. Level 1 and Level 2 methods that give the user the flexibility to input assumptions that differ from the ones used to create the tables and charts/nomographs in AC 150/5060 in order to represent the user's specific conditions.

2. A Level 4 capacity simulation model for estimating maximum sustainable throughput of complex airfield layouts, specifically designed for the purpose of estimating capacity, and that is available to the public.

To address these recommendations, the ACRP Capacity Spreadsheet Model was created in prototype form. Also, the MITRE *runway*Simulator was tested for purposes of validation, and identifying applications in which this model is recommended for use.

Chapter 1
BACKGROUND

This Report presents the findings of Airport Cooperative Research Program (ACRP) Project 03-17, “Evaluating Airfield Capacity.” This Report provides background information on the purpose of the research, the approach, key findings, and other conclusions. **However, the principal product of the research effort is the separately published Guidebook.**

The Guidebook serves as a review of current FAA guidance on airfield capacity, as well as highlighting other methodologies and tools that are currently available in the public and private domain relative to the topic. In addition, prototypes of new airfield capacity spreadsheet tools have been developed that provide additional mechanisms for calculating airfield capacities. The Guidebook also provides decision support tools for readers to use in selecting the appropriate level of modeling for a given application and set of circumstances. The Guidebook is intended to be used by airport operators, regional planning agencies, state aviation agencies, airport consultants, aviation researchers, the Federal Aviation Administration (FAA) planners, and other private and public aviation organizations.

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

The objective of this research is to develop a guidebook to assist airport planners with airfield and airspace capacity evaluation. The guidebook will address airport airfield and airspace capacity planning at all types of airports. The term “airfield” capacity refers to runways, taxiways, apron areas, and aircraft parking positions. “Airspace” capacity for this research is defined as the approach and departure procedures in the immediate vicinity of an airport that directly affects airfield capacity. The guidebook (1) includes an assessment of relevant methods and modeling techniques for evaluating existing and future capacity for airports beyond those outlined in the current the FAA’s Advisory Circular 150/5060-5 Airport Capacity and Delay (Advisory Circular) or the Airport Capacity Model; (2) identifies the limitations of the existing techniques; and (3) develops specifications for new models, tools, or enhancements. This guidebook will present capacity modeling guidelines that will improve the decision-making process for determining the appropriate level of modeling sophistication for a given planning study or capital improvement project and make the process more consistent from airport to airport. A functional prototype of one or more modeling tools will also be developed as part of this project.

SCOPE OF RESEARCH PROJECT

To meet the objectives of the research project, the work was conducted in three major steps: (1) inventory, (2) gap analysis, (3) model development and testing regime, and (4) preparation of Guidebook.

Step 1—Inventory

The research team assembled and reviewed published literature on the subject of airfield capacity. Additionally, the Team explored and reviewed existing modeling techniques. Factors which influence capacity were defined, and data sources for obtaining the information needed to complete a capacity analysis were described. Finally, the Team assembled a collection of case studies covering a wide range of capacity analyses for varying purposes, which used a variety of capacity analysis techniques, from which the Team drew conclusions about current capacity analyses.

Step 2—Gap Analysis

The gap analysis focused on identifying the limitations of the currently available modeling techniques and improvements needed to provide the level of accuracy and applicability of these techniques. Following this exercise, the recommended improvements were prioritized according to feasibility of implementation and importance.

Step 3—Model Development and Testing Regime

The research team developed a prototype tool in accordance with the findings the gap analysis. In addition, a testing and validation regime was executed on this new tool and a newly available capacity analysis tool.

Step 4—Develop the Guidebook

The research team developed the Guidebook using the results of Steps 1 through 3, as well as their collective professional experiences. The Guidebook was prepared as a standalone document that can be utilized by airport operators, regional planning agencies, state aviation agencies, airport consultants, aviation researchers, the FAA planners, and other private and public aviation organizations to select the appropriate method of capacity analysis for airports of all sizes.

Chapter 2
RESEARCH APPROACH

The research for ACRP 03-17, "Evaluating Airfield Capacity," was conducted in the following eight Tasks, following the steps, all originally defined in the Request for Proposals (RFP):

1. ***Collect Existing Pertinent Research.*** This task entailed an inventory of literature and research on capacity analysis, supplemented by the Team's professional experience, documenting the following:

   a. Airport case studies showing the range of capacity issues addressed by FAA, airports, and their consultants;

   b. The range of issues and factors which determine airport capacity;

   c. Research libraries of existing and on-going research on airport capacity issues, resulting in an annotated bibliography;

The documentation of this Task was submitted as part of the Interim Report, and is included in the appendices to this Report and/or the Guidebook.

2. ***Identify/Describe Data Requirements.*** This Task identified types and sources of data, defined the levels of modeling sophistication, and summarized factors affecting the choice of modeling sophistication level. This Task included the following steps:

   a. Identify and describe data requirements typically needed for various capacity analyses and key sources currently available for such data

   b. Identify and describe the types of projects for which capacity analyses are required or otherwise applicable, and recommend the modeling sophistication level for each type of project

   c. Summarize the factors that affect the choice of modeling sophistication level for a particular application requiring airfield capacity information

   This Task was documented in the Interim Report, and can now be found in the Guidebook and Final Report.

3. ***Gap Analysis***. This Task identified limitations in the currently available modeling techniques and recommendations for improvement, through the following steps:

   a. Levels of modeling sophistication identified in Task 2 were examined for operational constraints, scalability, cost effectiveness, data requirements, taxiway configurations, variability, and other considerations.

   b. Summarized identified gaps at each level of modeling sophistication

   This Task was documented in the Interim Report, and can now be found in the Guidebook and Final Report.

4. ***Prepare Interim Report.*** A report summarizing the findings of Tasks 1 through 3 was prepared for the purposes of documenting inventory-related tasks and reviewing identified gaps with the panel for prioritization for improvements in the second phase of the research.

5. ***Prioritize/Recommend Enhancements.*** Based on the findings of the gap analysis from Task 3, functional enhancements and improvements for the various levels of modeling sophistication were prioritized according to importance.

   a. Estimated the level of effort and resources to address the identified gaps

   b. Prioritize candidate model enhancements based on possibility of accomplishing the enhancement within the schedule and budget, and relative importance

   c. In collaboration with the Panel, selected model enhancements for all levels except Level 5.

6. ***Prepare Model Development Plan/Testing Regime.*** In this Task, a prototype tool was developed in accordance with the findings of Task 4. In addition, a testing regime was executed on this new tool and a newly available capacity analysis tool.

   a. Designed model interface and software architectural design

   b. Built functional model prototype

   c. Tested model's functional capability

7. ***Develop the Guidebook****.* The results of Tasks 1 through 6, as well as the collective professional experience of the research team, were combined to create the Guidebook. The Guidebook's main chapters document the background issues, existing models, new and newly available models, how to

select a modeling tool, and subsequent uses of capacity estimates. Detailed technical descriptions and is provided in the appendices.

8. ***Develop the Final Report.*** The Final Report contains technical detail and documentation not included within the Guidebook, completing documentation of the research.

DEVELOPMENT OF THE GUIDEBOOK

As the primary work product of this research effort, the Guidebook was prepared as a standalone document that can be utilized by airport operators, regional planning agencies, state aviation agencies, airport consultants, aviation researchers, the FAA, and other private and public aviation organizations to select the appropriate method of capacity analysis for airports of all sizes. The research team synthesized the documentation from the individual research Tasks, along with their professional experiences, into a Guidebook document with logical order and flow.

The Guidebook Chapters summarized below provide the fundamental useful results and recommendations of the research:

- **Chapter 1: Introduction and Background,** introduces the topics covered in the Guidebook, and provides the background needed to set the stage for further discussions, resolutions, and recommendations.

- **Chapter 2: Review of 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.

- **Chapter 3: Existing Airfield Capacity Evaluation Models,** 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 Models and Guidance,** describes the new spreadsheet models developed for this research project, as well as other newly available tools.

- **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 on specialty capacity evaluations is also provided.

- **Chapter 6: Subsequent Uses of Capacity Estimates,** describes the most common applications of airfield capacity information in aviation planning and decision making.

The Guidebook Appendices below elaborate on the subject matter of the research, providing further technical details and illustrations of concepts:

- **Appendix A: Capacity Spreadsheet Model User's Manual,** provides more technically detailed descriptions of features and instructions on using the ACRP Capacity Spreadsheet Model described in Chapter 4.

- **Appendix B: Essential References and Data Sources,** includes a description of publications and references important to issues related to airfield capacity, as well as a description of data sources for information needed for capacity analysis.

Chapter 3
FINDINGS AND APPLICATIONS

This chapter summarizes key findings of the research and identifies the likely applications for the Guidebook.

FINDINGS

The key findings of the research are fully documented in the Guidebook (published separately), which was the principal product of this research effort.

Need for Update in Capacity Analysis Methods. The main source of capacity analysis information and estimation techniques is contained in Advisory Circular 150/5060, which was published in 1983. Many developments necessitating a refresh of capacity analysis techniques have taken place since its publication. Existing capacity analysis methods have shortcomings in reflecting small airports and complex airfields. Additionally, improvements in computing power and data availability have made the development of more flexible and user-friendly models possible.

Two main improvements from existing methods of capacity analysis were identified, namely:

1. Level 1 and Level 2 methods that provide the flexibility for the user to input assumptions that differ from the ones used to create the Level 1 and 2 tables and charts/nomographs 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.

New Airfield Capacity Tools and Guidance. A prototype modeling tool intended to help airport planners understand and determine airfield capacity at a higher fidelity than AC 150/5060-5, but with much less effort than required to apply aircraft delay simulation models, such as SIMMOD and TAAM was developed as part of this research. Additionally, MITRE's *runway*Simulator was evaluated as the new "model of choice" for airports with complex airfields or air traffic control procedures. On average, *runway*Simulator produces capacity estimates that are 15% higher than actual observed runway throughput during saturated periods.

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. The guidance presented is not intended to provide a definitive unique answer to the question, "Which model should I use in a given situation?" Rather, it guides 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 to which model should be used, and many factors affect a decision that cannot be captured in a decision hierarchy. Nevertheless, the guidance should help the user narrow down the choices regarding which levels of modeling sophistication are appropriate to a reasonable set of options, any of which would be satisfactory.

APPLICATIONS

The principal product of the research, the Guidebook, was prepared as a standalone document that can be utilized by a variety of parties with interests in airfield capacity issues, including airport operators, regional planning agencies, state aviation agencies, airport consultants, aviation researchers, the FAA, and other private and public aviation organizations. It was assumed that users of this Guidebook have a general understanding of an airport's facilities and operations, especially regarding the airport for which a capacity analysis is being considered. This assumed basic level of understanding indicates that the user (1) knows how an airfield is typically operated in terms of aircraft taking off and landing, (2) can obtain at least minimal data on the airfield and air traffic to be analyzed, and (3) can use the recommended criteria for selecting an appropriate evaluation technique given the specific characteristics of the airport/airfield under consideration.

The Guidebook is intended to provide useful information for both novice and experienced airport planners to:

- Understand basic airfield elements and operations
- Understand the definition of airfield capacity
- Review the tools currently available, and the tools made available as a result of this research project, to estimate airfield capacity
- 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

Chapter 4

CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTED RESEARCH

The primary conclusions, recommendations, and best practices of this research are documented in the Guidebook, as summarized below:

1. Existing capacity analysis methods and techniques are outdated and must be refreshed to reflect developments in airfield geometries and procedures, as well as new advancements in computing and data availability.

2. New tools were developed and evaluated, including Level 1 and Level 2 methods that provide the flexibility for the user to input assumptions that represent an airport's specific conditions, and a Level 4 capacity simulation model for estimating maximum sustainable throughput of complex airfield layouts.

3. Selecting the appropriate level of modeling sophistication is not as easy as a "one size fits all" approach.

DISSEMINATION OF RESEARCH RESULTS

It is suggested that, in addition to the standard Transportation Research Board (TRB) distribution procedures, consideration be given to:

1. Submitting new releases for inclusion in *Centerlines*, the official publication of Airports Council International-North America (ACI-NA), *Airport Report*, the official publication of the American Association of Airport Executives (AAAE), and TRB aviation newsletter.

2. Seeking speaking opportunities before the national and regional conferences and/or annual meetings of organizations to present the results of this research.

RECOMMENDED NEXT STEPS AND FURTHER RESEARCH

The research team offers the following recommendations for next steps and further research that will augment and complement this research.

1. It is recommended that prototype ACRP capacity spreadsheet model developed as part of this research continue to be developed. The ACRP 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 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 model would also require the user to have significantly more data and knowledge of the airfield's operating conditions.

2. It is recommended that the findings and conclusions of this research, along with the findings of ACRP 03-20 be used by FAA to inform the development of the updated Advisory Circular on Airport Capacity and Delay.

ACRP 03-17

Evaluating Airfield Capacity

Appendix 1 to Final Report: Airfield Capacity Case Studies

June 29, 2012

LeighFisher

in association with

Landrum & Brown

Wilbur Smith Associates

George Mason University

University of California, Berkeley

Presentation & Design, Inc.

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TABLE

APPENDIX 1: AIRFIELD CAPACITY CASE STUDIES

This Appendix summarizes the review of studies related to airport capacity to identify issues addressed and tools and techniques used to prepare the studies. The case studies were selected to include a wide-ranging sample of applications of capacity and levels of modeling sophistication. However, these case studies are not meant to be a representative sample of the entire body of all capacity projects, but are intended to illustrate cases where different levels of modeling sophistication were used. In addition to the libraries of the Research Team members, interviews were conducted to confirm details about the studies. Although it may not be explicitly stated, most of these case studies considered both airfield and airspace capacity in the process of coordinating the study with air traffic and flight procedures specialists and in developing the assumptions for use in the analysis. Each case study is organized in the same fashion, into nine topics as follows:

1. Purpose – objective of the study
2. Models and Metrics – model used in the study (if any) and model input metrics
3. Data Collected (Calibration/Validation) – empirical data collected to validate model results
4. Capacity Time Interval – time period for capacity calculation (annual, daily, hourly, 15 minute)
5. Demand-capacity comparison – comparison of model results to empirical date
6. Estimating Aircraft Delay – use of capacity estimates in estimating delay (if relevant)
7. Human factors considerations – inclusion of pilot or controller human factors in capacity estimates
8. Consideration of NextGen technologies – inclusion of future technologies to enhance capacity
9. Relevance to this research – significance of the case study to the research

Not all topics are relevant to each case study, for example, a study may not have addressed NextGen, in which case the description for the topic will read “N/A.”

Relevancy of Nine Topics to Size of Airport – Understanding the Needs of Small Airports

The foregoing nine topics examined for each case study provide a means of comparison of the case studies to determine where there are commonalities and differences. In reviewing the case studies and the compilation of data, the size of the airport under study typically revealed a simplistic result – smaller airports as defined by either operational activity or type of service (passenger or general aviation) utilized less sophisticated modeling techniques. The reasons for use of the specific techniques for these airports could be attributed to the following:

- Purpose of the study was broader in scope and recognition that airfield capacity was not a significant issue in the overall study
- Lack of reliable data on operational activity to accurately assess whether airfield capacity was an issue
- Type of facilities available at the airports (taxiway and number of exits, instrument approach, ATCT, radar coverage, ATC remote communications)
- Time and resources available for the study of capacity issues

Unless airfield capacity is a recognized issue at the airport, a detailed capacity analysis is typically not undertaken. At uncontrolled airports, airfield capacity is realized and recognized only when issues such as incursions, near misses, and general discussion

Index to Case Studies

An index to the case studies is provided in Table 1. To organize the case studies considered, each case study was categorized into one of six categories, (1) master plans, (2) system plans, (3) capacity studies, (4) environmental studies (5) FAA studies, and (6) academic reports. Each case study was examined to determine if it addressed a series of characteristics, described below, in order to classify the studies and identify gaps.

- **Applications** – capacity benefits, aircraft delay, future technologies, environmental constraints, system planning
- **Domains** – runways, taxiways, gates, terminal airspace, national airspace system (NAS)
- **Capacity metrics** – hourly throughput, empirical capacity, service volume
- **Models** – table lookup, analytical, simulation

Table 1
ACRP PROJECT 03-17—EVALUATING AIRFIELD CAPACITY
Index to Case Studies—Keywords
Airport Planning Studies

		Applications					Domains					Capacity metrics			Models		
	Case study (short title)	Capacity benefits	Aircraft delay	Future technologies	Environmental constraints	System planning	Runways	Taxiways	Gates	Terminal airspace	NAS	Hourly throughput	Empirical capacity	Service volume	Table-lookup	Analytical	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				X
4	Master Plan (BWI)	X	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	X	
	Capacity Studies																
7	Update of Airfield Analysis (HOU)	X	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			X	
11	Airside Capacity Study (JFK)	X		X			X	X	X			X	X			X	
12	Delay Reduction Study (JFK)	X	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			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		X	
	Academic and Research Studies																
20	Low Visibility Landing and Surface Operations Runway Occupancy Time	X					X						X			X	
21	Optimal Level of Operations on an Arrivals Only Runway						X						X			X	
22	Computer Simulation Model for Airplane Landing Performance	X					X						X				X
23	Improvements in Simple Models for Estimating Runway Capacity	X					X						X			X	
24	Validation of Runway Capacity Models						X					X				X	
25	Delay Impacts of an Airport Enhancement (Detroit)	X		X			X						X			X	
26	Scenario-Based Management of Air Traffic Flow		X			X	X			X	X		X			X	X
27	North Airfield Safety Study (Los Angeles)	X	X				X	X				X					X

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AIRFIELD CAPACITY CASE STUDIES
Master Plans

1. Airport Master Plan, Beaufort County Airport (ARW), Wilbur Smith Associates (2009)

KEY WORDS: Aircraft delay, runways, hourly throughput, service volume, table lookup, analytical models.

TOPIC	DESCRIPTION
1. Purpose	Beaufort County Airport (ARW), small general aviation airport near the town of Beaufort, South Carolina. • Classified in the FAA NPIAS as a "general aviation" airport. • ARW has no commercial air carrier service. • ARW has one runway supported by partial parallel taxiway system. • ARW has non-precision instrument approaches but no ATCT. The purpose of this particular capacity analysis for ARW was to determine if aviation activity levels projected within the master plan update planning horizon would approach the capacity of the existing and planned airfield system.
2. Model and Metrics	**Models:** FAA AC 150/5060-5, Airport Capacity and Delay **Metrics:** 1. Annual Service Volume (ASV) 2. Hourly service capacity
3. Data Collected (Calibration/Validation)	1. Meteorological Conditions 2. Percent of Touch-and-Go's 3. Aircraft Fleet Mix 4. Percent Arrivals 5. Projected Annual Airport Operational Demand Levels
4. Capacity Time Interval	1. Annual 2. Peak Hour/Average Day/Peak Month
5. Demand-capacity Comparison	The projected annual operational demand levels were compared with existing and projected ASV capacities to assess the relationship between demand and capacity.
6. Estimating Aircraft Delay	The primary performance metrics were average delay per aircraft and total annual delay estimated using ratio of annual demand to ASV.
7. Human factors Considerations	Human factors inherent to operational procedures were included in the form of aircraft separation requirements in an uncontrolled airport environment.
8. Consideration of NextGen Technologies	The effects of future NextGen technologies on airfield capacity were not considered in this study.
9. Relevance to this Research	Provides a practical application of a standard airport capacity analysis for low activity general aviation airport without an ATCT.

AIRFIELD CAPACITY CASE STUDIES
Master Plans

2. Airport Master Plan, Chandler Municipal Airport (CHD), Wilbur Smith Associates (2006)

KEY WORDS: Aircraft delay, runways, hourly throughput, service volume, table lookup, analytical models.

TOPIC	DESCRIPTION
1. Purpose	Chandler Municipal Airport (CHD), a very active general aviation airport located within the Phoenix, Arizona metropolitan area. • Classified in FAA NPIAS) as a "reliever" airport for Phoenix Sky Harbor International Airport. • Has two runways supported by an appropriate taxiway system. • Has an ATCT and advanced precision instrument approaches. To determine if aviation activity levels projected within the master plan would exceed the capacity of the existing and planned airfield system.
2. Model and Metrics	**Models:** FAA AC 150/5060-5, Airport Capacity and Delay **Metrics:** 1. Annual Service Volume (ASV) 2. Hourly service capacity
3. Data Collected (Calibration/Validation)	1. Meteorological Conditions 2. Percent of Touch-and-Go's 3. Aircraft Fleet Mix 4. Percent Arrivals 5. Projected Annual Airport Operational Demand Levels
4. Capacity Time Interval	1. Annual 2. Peak Hour/Average Day/Peak Month
5. Demand-capacity Comparison	The projected annual operational demand levels were compared with existing and projected ASV capacities
6. Estimating Aircraft Delay	The primary performance metrics used to estimate airfield performance was average delay per aircraft and total annual delay estimated using the ratio of annual demand to ASV
7. Human factors Considerations	Human factors inherent to ATCT operational procedures were included in the form of aircraft separation requirements, as specified in FAA Order JO7110.65, Air Traffic Control. Additionally, ATCT operational patterns were considered with respect to the CHD's two runways and how the airport's significant flight training operational levels are managed and accommodated by the existing facilities.
8. Consideration of NextGen Technologies	The effects of future NextGen technologies on airfield capacity were not considered in this study.
9. Relevance to this Research	Provides case study of a practical application of a standard airport capacity analysis for an active general aviation airport with an ATCT.

AIRFIELD CAPACITY CASE STUDIES
Master Plans

3. Master Plan Update, Memphis International Airport (MEM), LeighFisher (2008)

KEY WORDS: Aircraft delay, runways, taxiways, terminal airspace, hourly throughput, empirical capacity, simulation models.

TOPIC	DESCRIPTION
1. Purpose	To determine if aviation activity levels forecast for the Master Plan Update planning horizon would exceed the capacity of the airfield system.
2. Model and Metrics	**Model:** Total Airspace and Airport Modeller (TAAM) **Metrics:** 1. Average design day delay per aircraft operation 2. Number of operations missing the FedEx sort window
3. Data Collected (Calibration/Validation)	**Data:** 1. Aircraft flight schedules 2. Air traffic control and ground control rules **Calibration/Validation:** 1. Created a series of validation flight schedules in which the levels of hourly demand far exceeded the anticipated capacity of the simulated runway system and ran these schedules in TAAM 2. Compared the resulting runway throughput rates to actual runway throughput rates reported in the FAA's Aviation System Performance Metrics (ASPM) database
4. Capacity Time Interval	Runway throughput and capacity was considered on an hourly basis; flight schedules were developed for a design day (average day of the peak passenger month, and average day peak month of cargo activity).
5. Demand-capacity Comparison	Average annual airport delays of 4 to 6 minutes, as prescribed in the NPIAS, were considered to be the threshold for undertaking major capacity enhancement projects.
6. Estimating Aircraft Delay	Estimates of average aircraft delay, measured in minutes per operation, were computed with consideration of percent occurrence of runway use configuration and weather conditions.
7. Human Factors Considerations	• Minimum separations specified in FAA Order JO7110.65 were "buffered" to account for typical variations in separations • The buffer accounts for air traffic controllers' need to separate aircraft by distances that are somewhat higher than absolute minimums in order to avoid separation violations.
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	This study is an example of applying airfield simulation to estimating the need for additional airfield capacity at existing and future demand levels on the basis of estimated aircraft delays. In addition, this study captures the reductions in delay associated with changes in procedures and infrastructure changes in procedures.

AIRFIELD CAPACITY CASE STUDIES
Master Plans

4. Master Plan, Thurgood Marshall International Airport (BWI) Master Plan, Landrum & Brown (2010)

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, gates, hourly throughput, empirical capacity, simulation models.

TOPIC	DESCRIPTION
1. Purpose	The State of Maryland Aviation Administration is preparing a 25 year Master Development Plan for BWI. This plan proposes to balance airside, terminal and landside capacity throughout the 25 year development period. Previous construction brought terminal and roadway capacity up to a capacity of 30 million annual passengers. However, runway capacity is forecast to lag other airport components. The purpose of this study was to determine configuration of new runway and its capacity, and determine timing of future runway development need.
2. Model and Metrics	1. **Model:** SIMMOD 2. **Metrics:** Hourly runway capacity and average annual delay per aircraft operation.
3. Data Collected (Calibration/Validation)	1. FAA Aviation System Performance Metrics (ASPM) 2. Airport Noise Measurement System (ANOMS) 3. Existing and future terminal gate layouts and airline assignments 4. Taxiway capacity available for departure queue management by runway (establish thresholds for gate holding)
4. Capacity Time Interval	Hourly runway throughput and annual aircraft operations.
5. Demand-capacity Comparison	20 minutes average delay per aircraft operation used to define maximum annual throughput
6. Estimating Aircraft Delay	FAA SIMMOD Model
7. Human Factors Considerations	Ability of air traffic controllers to time departure operations on long-intersections with arrival runways. Used simulation animations to confirm operations with air traffic control managers. Plotted simulated aircraft flight tracks to demonstrate airspace utilization.
8. Consideration of NextGen Technologies	None
9. Relevance to this Research	Use of simulation animations to demonstrate various operating scenarios to validate simulation modeling of future demand conditions.

AIRFIELD CAPACITY CASE STUDIES
System Plans

5. Airport System Plan Update (New Mexico), Wilbur Smith Associates (2009)

KEY WORDS: System planning, runways, taxiways, analytical models.

TOPIC	DESCRIPTION
1. Purpose	The New Mexico Department of Transportation Aviation Division conducted an analysis of the state's 52 public use airports. • 31 airports included in the NMASPU have multiple runways, 80 percent of which have a paved asphalt surface • 51 percent have a full parallel taxiway • 10 system airports have a precision approach and 20 system airports have a non-precision approach To determine if aviation activity levels projected within the 20-year system planning horizon would exceed the annual capacity of the existing and planned airfield system for each airport.
2. Model and Metrics	FAA Advisory Circular (AC) 150/5060-5, *Airport Capacity and Delay*. Specifically, annual service volume (ASV) was used. WSA developed a spreadsheet model that adjusts the AC capacities for the availability of specific items such as parallel taxiway, runway surface, ATCT, and instrument approaches **Models:** 1. FAA AC 150/5060-5, Airport Capacity and Delay 2. WSA ASV calculation spreadsheet model **Metrics:** 1. Annual Service Volume (ASV)
3. Data Collected (Calibration/Validation)	1. Percent of Touch-and-Go's 2. Aircraft Fleet Mix 3. Projected Annual Airport Operational Demand Levels
4. Capacity Time Interval	Annual
5. Demand-capacity Comparison	The projected annual operational demand levels were compared with existing and projected ASV capacities to assess the relationship between demand and capacity.
6. Estimating Aircraft Delay	Total annual delay estimated using the ratio of annual demand to ASV.
7. Human factors Considerations	Human factors inherent to ATCT operational procedures were included in the form of aircraft separation requirements, as specified in FAA Order JO7110.65, Air Traffic Control. Additionally.
8. Consideration of NextGen Technologies	The effects of future NextGen technologies on airfield capacity were not considered in this study.
9. Relevance to this Research	Provides case study of a practical application of a standard statewide airport system planning capacity analysis.

AIRFIELD CAPACITY CASE STUDIES
System Plans

6. Regional Airport System Demand Study (New York/New Jersey), Landrum & Brown (2006)

KEY WORDS: System planning, runways, taxiways, gates, hourly throughput, empirical capacity, table lookup, analytical models.

TOPIC	DESCRIPTION
1. Purpose	Study was conducted simultaneously for three clients: The Port Authority of New York and New Jersey, The State of New York Department of Transportation and the Delaware Valley Regional Planning Commission. The study forecast future demand and capacity for nine commercial airports in the New York Region (JFK, EWR, LGA, HPN, SWF, ISP, ACY, TTN, and ABE). The study concluded that the three central airports have insufficient airfield capacity to handle future demand beyond 2010, while the six sub-urban airports had sufficient airfield capacity to handle future demand. However, the six suburban airports lacked terminals and landside facilities. In addition, the six suburban airports were quite distant from the bulk of the region's demand. The region lacked high-speed surface transportation infrastructure to make the suburban airports more accessible to the demand within the region's core. To determine needs and locations for additional airport capacity to meet 20 year demand within the New York/ New Jersey region.
2. Model and Metrics	1. **Model:** Queuing models and the FAA airport capacity handbook 2. **Metrics:** Hourly runway capacity and average annual delay per aircraft operation.
3. Data Collected (Calibration/Validation)	1. FAA Aviation System Performance Metrics (ASPM) 2. Port Authority CATER System 3. Existing and future terminal gate layouts and airline assignments 4. Taxiway capacity available for departure queue management by runway (establish thresholds for gate holding)
4. Capacity Time Interval	Hourly runway throughput and annual aircraft operations.
5. Demand-capacity Comparison	Hourly runway demand and throughput for arrivals and departures and annual demand and capacity.
6. Estimating Aircraft Delay	Dynamic linked queuing models evaluating daily demand and capacity on a five minute time slice.
7. Human Factors Considerations	None.
8. Consideration of NextGen Technologies	None.
9. Relevance to this Research	Wide-range of commercial airport capacity issues including airspace, airfield, apron, terminal, and landside.

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

7. Update of Airfield Analysis, William P. Hobby Airport (HOU), LeighFisher (2008)

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, hourly throughput, empirical capacity, service volume, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To estimate the benefits of proposed airfield expansion and reconfiguration alternatives.
2. Model and Metrics	**Model:** FAA Airfield Capacity Model (ACM), formulas and Advisory Circular AC 150/5060-5 **Metrics:** 1. Hourly runway capacity 2. Annual Service Volume (ASV) 3. Average Aircraft Delay 4. Numbers and categories of runway incursions
3. Data Collected (Calibration/Validation)	**Data:** 1. PASSUR data on runway use 2. ASPM data on airfield throughput rates and aircraft delays 3. Data on runway incursions from the Regional Runway Safety Office **Calibration/Validation:** Compared the resulting hourly runway capacity estimates with actual runway throughput rates reported in ASPM
4. Capacity Time Interval	Runway throughput and capacity was considered on an hourly basis. Annual Service Volumes were estimated using formulas in AC.
5. Demand-capacity Comparison	Comparisons were made in the form of demand/capacity ratios: namely the ratio of total annual operations to ASV.
6. Estimating Aircraft Delay	Average aircraft delays were estimated using the delay curves in the AC and were used in benefit-cost analyses of proposed improvements.
7. Human Factors Considerations	The airfield improvements were judged partly on the basis of their potential for mitigating the risk of runway incursions based on a review of actual data on runway incursions at various points on the airfield.
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	This study is an example of using ACM and ASV along with delay curves in AC for estimating delays for a BCA, and of comparing projects on the basis of their capacity enhancement potential and potential for reducing the risk of runway incursions.

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

8. Airport Expansion Feasibility Study, Puebla International Airport (PBC), LeighFisher (2009)

KEY WORDS: Capacity benefits, runways, taxiways, hourly throughput, service volume, analytical models.

<table>
<tr><th>TOPIC</th><th>DESCRIPTION</th></tr>
<tr><td>1. Purpose</td><td>To estimate the Airside facilities that would be required at the Airport to accommodate the forecast level of aircraft operations.</td></tr>
<tr><td>2. Models and Metrics</td><td>Models:
1. Spreadsheets for estimating hourly runway capacity on the basis of runway occupancy times of arrivals and departures.
2. Formulas for estimating Annual Service Volume (ASV) from existing Advisory Circular 150/5060-5
Metrics:
Arrival runway occupancy times, departure runway occupancy times, hourly runway capacity, and ASV:
<table>
<tr><th>Parallel Taxiway</th><th>Hourly Runway Capacity</th><th>ASV</th></tr>
<tr><td>None</td><td>18</td><td>62,000</td></tr>
<tr><td>1/3</td><td>23</td><td>81,000</td></tr>
<tr><td>2/3</td><td>31</td><td>107,000</td></tr>
<tr><td>Full</td><td>41</td><td>132,000</td></tr>
</table></td></tr>
<tr><td>3. Data Collected (Calibration/Validation)</td><td>• Measurements of existing runway occupancy times
• Interviews with Airport operations staff and tower controllers</td></tr>
<tr><td>4. Capacity Time Interval</td><td>Hourly runway capacities and annual service volume (ASV).</td></tr>
<tr><td>5. Demand-capacity Comparison</td><td>Comparisons were made of (1) forecasted peak-hour aircraft operations with estimated hourly runway capacity, and (2) forecasted annual aircraft operations with estimated ASV. These comparisons were made for having no parallel taxiway, a partial-length parallel taxiway, and a full-length parallel taxiway</td></tr>
<tr><td>6. Estimating Aircraft Delay</td><td>Aircraft delays were not estimated in the study.</td></tr>
<tr><td>7. Human Factors Considerations</td><td>N/A</td></tr>
<tr><td>8. Consideration of NextGen Technologies</td><td>N/A</td></tr>
<tr><td>9. Relevance to this Research</td><td>This study is an example of estimating effects on hourly runway capacity and ASV of having no-, partial-, and full-length parallel taxiway.</td></tr>
</table>

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

9. Ultimate Airfield Capacity Study, Oakland International Airport (OAK), LeighFisher (2009)

KEY WORDS: Aircraft delay, future technologies, environmental constraints, runways, simulation models.

TOPIC	DESCRIPTION
1. Purpose	The purpose of this study was to quantify the maximum practical capacity of the Airport's airfield in terms of annual numbers of aircraft operations and passengers.
2. Model and Metrics	**Model:** An enhanced derivative of the widely used airport and airspace simulation model (SIMMOD) called SIMMOD *PRO!* **Metrics:** 1. Average design day delay per aircraft operation 2. A design day schedule reflecting the practical airfield capacity based on maximum delays and schedule-keeping capability.
3. Data Collected (Calibration/Validation)	**Data:** 1. Airfield improvements recommended in the Airport Master Plan 2. ADPM passenger airline aircraft operations (departures and arrivals) in August 2008 3. Air traffic control and ground control rules and morning noise-abatement-departure procedures **Calibration/Validation:** Three future demand levels were developed to encompass the probable practical daily capacity of the OAK airfield – 1,080, 1,130, and 1,180 total aircraft operations, which equate to 700, 750, and 800 daily passenger airline aircraft operations. These schedules were then run in SIMMOD *PRO!*
4. Capacity Time Interval	Daily – recommended the 750 daily airline operations level as the maximum practical airfield capacity of the Airport, which corresponds to 1,130 total daily aircraft operations of all types and on all runways
5. Demand-capacity Comparison	SIMMOD *PRO!* is a discrete event simulation model that (1) generates aircraft movements from detailed flight schedules; (2) separates movements based on assumed ATC rules, runway uses, weather conditions, and flight procedures (which essentially determine airfield throughput capacity); and (3) keeps track of the resulting aircraft delays.
6. Estimating Aircraft Delay	Aircraft delays were estimated using SIMMOD *PRO!*.
7. Human Factors Considerations	Minimum in-trail separations are hard to reach in part due to controller workload limitations for merging departures from two different airports.
8. Consideration of NextGen Technologies	Assumed that (1) use of RNP for precision approaches to Runway 11 could eliminate the need for the ILS hold line for the departure queue, and (2) RNAV departure procedures could mitigate dependency between SFO and OAK noise abatement departure operations
9. Relevance to this Research	This study is an example of locally defined practical airfield capacity (or service volume) based on delay and schedule-keeping capability.

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

10. Analysis of Airside Capacity and Gate Capacity, San Francisco International Airport (SFO, LeighFisher (2008)

KEY WORDS: Aircraft delay, runways, gates, hourly throughput, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To perform a high-level demand-capacity analysis of potential future flight schedules that reflects new service by several low-cost carriers. A related purpose is to analyze the relative capacities of the runways and the gates at SFO.
2. Models and Metrics	**Models:** 1. A high-level queuing model based on cumulative arrival demand and capacity curves was used. This model is well suited to saturated arrival conditions and is useful for performing comparative analyses of different arrival flight schedules. 2. Runway capacity information for SFO was obtained from a paper: "Managing Uncertainty in the Single Airport Ground Holding Problem using Scenario-based and Scenario-free Approaches" by Barry Liu and Mark Hansen, 11/5/06, which identified six capacity "clusters" that represent typical patterns of 15-minute airport arrival rates over the hours of the day. **Metrics:** 1. Hourly AARs, which were derived from the 15-minute AARs used in the foregoing "cluster analysis," were used to estimate hourly runway capacities 2. Estimated the number of gates that balances the Airport's runway capacity
3. Data Collected (Calibration/Validation)	Obtained data from the FAA Airspace System Performance Metrics (ASPM) database on scheduled aircraft operations, aircraft delays, and flight cancellations.
4. Capacity Time Interval	Runway throughput capacity was considered on an hourly basis but was based on 15-minute AAR data.
5. Demand-capacity Comparison	Hourly arrival demand-capacity comparisons were made in the cumulative curve queuing model for purposes of estimating aircraft delay.
6. Estimating Aircraft Delay	Aircraft arrival delays were estimated using the cumulative-curve queuing model.
7. Human Factors Considerations	The AARs used in the analysis were called out by the ATCT controllers on the basis of historical performance under specific operating conditions, which reflect effects of interleaving departures and voice communication constraints.
8. Consideration of NextGen Technologies	The foregoing cumulative-curve delay analysis methodology was used to estimate the benefits of Simultaneous Offset Instrument Approach (SOIA) procedure to Runways 28R and 28L.
9. Relevance to this Research	This study is an example of the cumulative-curve techniques for demand-capacity-delay analysis of a flight schedule and ways of comparing airfield capacity with gate capacity.

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

11. Airside Capacity Study, New York John F. Kennedy International Airport (JFK), Landrum & Brown (2008)

KEY WORDS: Capacity benefits, future technologies, runways, taxiways, gates, hourly throughput, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	The Port Authority of New York & New Jersey was concerned that developing all seven terminals to their full capacity would exceed the capacity of the runway and taxiway system. Identify the gate, apron, and aircraft parking capacity capable of being supported by existing and future airfield capacity with airspace and Next-Gen improvements.
2. Model and Metrics	Consultant linked runway queue and gate capacity models. **Metrics:** 1. Hourly runway capacity values evaluated every five minutes (VMC, MVMC and IMC) 2. Gate counts 3. Number of inbound and outbound taxiing aircraft (used to establish gate hold thresholds) 4. Queuing space for each departure runway
3. Data Collected (Calibration/Validation)	1. PANYNJ CATER System 2. FAA Aviation System Performance Metrics (ASPM) 3. Existing and future terminal gate layouts and airline assignments 4. Taxiway capacity available for departure queue management by runway
4. Capacity Time Interval	Queuing and gate capacity models use five minute time-slice. Hourly runway capacity estimated from CATER and FAA ASPM. Airspace improvements allowed greater use of third runway to add peak period arrival and departure capacity. Next-Gen improvements allowed more hourly operations per runway for existing runway configurations (TBFM improvements).
5. Demand-capacity Comparison	Conducted on a five minute time-slice within queuing model.
6. Estimating Aircraft Delay	Dynamic Queuing Model which examines scheduled and queued demand for arrivals and departures and chooses an airfield mode (arrival preference, departure preference, or balanced capacity).
7. Human Factors Considerations	None.
8. Consideration of NextGen Technologies	Time Based Flow Management and airspace configuration changes assumed to allow JFK to operate at 96 operations per hour.
9. Relevance to this Research	Provides example that links runway, taxiway, and gate capacities to confirm airport development concepts and identify additional facility needs.

AIRFIELD CAPACITY CASE STUDIES
Capacity Studies

12. Delay Reduction Study, New York John F. Kennedy International Airport (JFK), LeighFisher (2008)

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, terminal airspace, hourly throughput, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To determine the delay reduction benefits associated with the proposed taxiway improvement projects defined in the Port Authority's Delay Reduction Program for John F. Kennedy International Airport.
2. Models and Metrics	**Models:** 1. Analytical techniques, such as the FAA Runway Capacity and Annual Delay Model used in conjunction with ASPM data 2. Spreadsheet-based methods for estimating effects of airspace miles-in-trail departure fix restrictions on departure capacity **Metrics:** 1. Hourly AARs and ADRs from ASPM were used to estimate various capacities defined as points on a Pareto frontier for input to the Annual Delay Model. 2. Estimated increases in departure throughput capacity with the taxiway improvements through enhanced flexibility to re-sequence departures and avoid back-to-back departures to the same fix.
3. Data Collected (Calibration/Validation)	• Inputs and data were gathered from interviews with stakeholders • Potential operational benefits of each proposed taxiway project were expressed in terms of: – Reductions in departure-departure separations – Increases in departure rates – Reductions in dependencies between departures and arrivals – Increases in queuing space for staging departures
4. Capacity Time Interval	Runway throughput and capacity was considered on an hourly basis.
5. Demand-capacity Comparison	Hourly demand-capacity comparisons were made in the Annual Delay Model.
6. Estimating Aircraft Delay	• Departure-priority departure capacities were increased between 1 to 4 additional departures depending on the estimated capacity enhancement provided by each taxiway project • The Annual Delay Model was used for each of the taxiway improvement cases to estimate reductions in average annual delay
7. Human Factors Considerations	The assumed miles-in-trail restrictions are due in part to ATC controller workload and sector capacity constraints.
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	This study is an example of using empirical data and spreadsheets to estimate capacity benefits of improved taxiways for mitigating departure capacity constraints due to in-trail spacing requirements.

AIRFIELD CAPACITY CASE STUDIES
Environmental Studies

13. Part 161 Study, Bob Hope Airport (BUR), LeighFisher (2009)

KEY WORDS: Environmental constraints, system planning, runways, terminal airspace, hourly throughput, table lookup, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To estimate hourly runway capacities and airspace fix capacities to compare with the numbers of diverted operations expected to be received by the various airports and fixes as the result of the FAR Part 161 recommendations. This capacity analysis was performed at a very high-level designed to give very conservative estimates of runway and fix capacities
2. Models and Metrics	**Models:** 1. For runway capacities, except for LAX, high-level estimates were obtained from Advisory Circular AC 150/5060-5 2. For LAX, the estimates of hourly runway capacity were obtained from the FAA 2004 Airport Benchmark Capacity Report 3. For airspace fix capacity, a very high-level estimate was made by assuming an in-trail separation at the airspace fix of 7 nautical miles and an aircraft speed of 250 knots, which yields a very conservative estimate of airspace fix capacity of 36 arrivals or departures per hour. **Metrics:** Hourly capacities of airport runways and airspace fixes
3. Data Collected (Calibration/Validation)	Tables summarizing the numbers of diverted operations by day, evening, and night from and to each affected airport expected to occur with the FAR Part 161 recommendations.
4. Capacity Time Interval	Runway throughput and airspace fix capacity were considered on an hourly basis.
5. Demand-capacity Comparison	• In comparing diverted operations with airspace fix capacity, comparisons were made of either the number of diverted arrivals or departures, whichever is larger, with the airspace fix capacity, because airspace fixes generally handle either arrivals or departures, but not both. • In addition, the conservative assumption was made that, because many of these diversions could occur in early-morning and late-evening hours, comparisons were made of the number of diverted operations with just the IFR hourly capacity of each airport.
6. Estimating Aircraft Delay	Aircraft delays were not estimated in the study
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	This study is an example of ad hoc spreadsheet analysis of airspace fix capacities versus runway capacities and numbers of diverted operations resulting from FAR Part 161 recommendations.

AIRFIELD CAPACITY CASE STUDIES
Environmental Studies

14. Environmental Impact Statement for the 2nd Parallel Air Carrier Runway at Fort Lauderdale-Hollywood International Airport (FLL), Landrum & Brown (2009)

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, gates, hourly throughput, empirical capacity, simulation models.

TOPIC	DESCRIPTION
1. Purpose	Fort-Lauderdale-Hollywood International Airport (FLL) has experienced rapid growth of passenger volumes and air carrier aircraft operations, which has resulted in rapidly escalating delays. The airport operator proposes to replace an existing general aviation runway with a larger air carrier runway which could increase aircraft operations capacity by 60 to 100%. State the purpose and need; evaluate alternative airfield expansion alternatives and assess the environmental impacts.
2. Model and Metrics	1. **Models:** • Queuing models and the FAA airport capacity handbook • SIMMOD to evaluate effect on runway approach separations of single parallel taxiway and back taxi to reach terminal area • Airport sponsor provided TAAM output files for several alternatives which were used to calibrate other models and assess departure queue lengths 2. **Metrics:** • Hourly runway capacity • Annual capacity • Average annual delay per aircraft operation.
3. Data Collected (Calibration/Validation)	1. FAA Aviation System Performance Metrics (ASPM) 2. TAAM output files from previous studies 3. Existing and future terminal gate layouts and airline assignments 4. Taxiway capacity available for departure queue management by runway (establish thresholds for gate holding)
4. Capacity Time Interval	Hourly runway throughput and annual aircraft operations.
5. Demand-capacity Comparison	Hourly runway demand and throughput for arrivals and departures and annual demand and capacity.
6. Estimating Aircraft Delay	Dynamic linked queuing models evaluating daily demand and capacity on a five minute time slice.
7. Human Factors Considerations	None
8. Consideration of NextGen Technologies	None
9. Relevance to this Research	Study assessed interaction of taxiway capacity and runway capacity and division of demand between runways (runway length and width variances).

AIRFIELD CAPACITY CASE STUDIES
Environmental Studies

15. Part 150 Study, Landrum & Brown, , Cincinnati/Northern Kentucky International Airport (CVG), Landrum & Brown (1999)

KEY WORDS: Capacity benefits, aircraft delay, runways, hourly throughput, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Case Study Context	The Kenton County Airport Board needed to update the airport's noise plan after opening the new runway. The Part 150 study evaluated new noise abatement procedures for both daytime and night time operations.
2. Purpose	Determine the effect of noise abatement procedures on runway capacity.
3. Model and Metrics	1. Model: Analytical models (spreadsheets) 2. Metrics: Hourly runway capacity and average annual delay per aircraft operation.
4. Data Collected (Calibration/Validation)	1. FAA Aviation System Performance Metrics (ASPM) 2. Airport Noise Measurement System (ANOMS)
5. Capacity Time Interval	Hourly runway throughput and annual aircraft operations.
6. Demand-capacity Comparison	Hourly runway demand and throughput for arrivals and departures (serving the hub airline) and annual demand and capacity
7. Estimating Aircraft Delay	Spreadsheet Delay Model (SADM)
8. Human factors Considerations	Ability to accurately navigate short final approach procedures
9. Consideration of NextGen Technologies	None
10 Relevance to this Research	Example of evaluating the availability of multiple headings on runway capacity.

AIRFIELD CAPACITY CASE STUDIES
FAA Studies

16. Advisory Circular AC-150/5060-5, Airport Capacity and Delay, Federal Aviation Administration (1983)

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, gates, hourly throughput, service volume, service volume, table lookup, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To provide a framework for computing airport capacity and aircraft delay for airport planning and design at several different levels of detail/sophistication and for a variety of runway configurations and weather conditions.
2. Model and Metrics	**Model:** FAA Airfield Capacity Model (ACM), equations, tables, nomographs, charts, and graphs **Metrics:** 1. Hourly capacity airport capacity 2. Hourly capacity of the runway, taxiway, and gate group components 3. Taxiway capacity 4. Gate capacity 5. Annual Service Volume (ASV) 6. Annual aircraft delay
3. Data Collected (Calibration/Validation)	**Data:** 1. Fleet mix 2. Runway-use configurations and occurrence 3. Average daily demand, average peak hour demand, annual demand 4. Number of air carrier and general aviation operations **Calibration/Validation:** N/A
4. Capacity Time Interval	Runway capacity is calculated on an hourly basis.
5. Demand-capacity Comparison	ASV is compared to historical or forecast traffic levels to calculate aircraft delay and the need to increase capacity.
6. Estimating Aircraft Delay	Average delay is calculated using either a lookup table or a set of delay curves expressing average delay as a function of the ratio of demand to capacity.
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	This study provides several levels of modeling sophistication for estimating airfield capacity including table lookup, nomographs, and equations.

AIRFIELD CAPACITY CASE STUDIES
FAA Studies

17. Capacity Enhancement Plan Update, Federal Aviation Administration Technical Center and Memphis-Shelby County Airport Authority, October 1997

KEY WORDS: Capacity benefits, aircraft delay, runways, hourly throughput, practical capacity, simulation models.

TOPIC	DESCRIPTION
1. Purpose	Typical example of Capacity Enhancement Plans prepared by Airport Capacity Design Teams composed of FAA representatives from the Office of System Capacity, the Technical Center, Air Traffic, Southern Region, Memphis ADO, Memphis International Airport, airlines, and other users.
2. Model and Metrics	**Model(s):** FAA Airfield and Airfield Delay Simulation Model (ADSIM) and Runway Delay Simulation Model (RDSIM **Metrics:** 1. Hourly airport capacity corresponding to an average aircraft delay of 4 min. per operation 2. Total aircraft delays, average aircraft delays, average annual aircraft delay, and annual aircraft delay costs
3. Data Collected (Calibration/Validation)	**Data:** 1. Occurrence of weather conditions 3. Hourly, daily, and annual traffic data and aircraft mix **Calibration/Validation:** 1. ADSIM and RDSIM were considered validated models by FAA 2. Hourly capacities were calibrated against hourly traffic data
4. Capacity Time Interval	Practical airfield capacities were considered on an hourly basis. Aircraft delays were considered on an average daily and average annual basis.
5. Demand-capacity Comparison	Airfield capacities and aircraft delays were calculated for baseline conditions (existing demand and operating procedures). Benefits of proposed improvements were measured against these baseline capacities and delays.
6. Estimating Aircraft Delay	Delays were estimated using ADSIM and RDSIM for both baseline conditions and proposed improvements.
7. Human Factors Considerations	The only human factors considerations were the various buffers built into ADSIM and RDSIM, which are expressed as a function of input standard deviations of aircraft separations, runway occupancy times, and pilot response times.
8. Consideration of NextGen Technologies	Various procedural changes were considered including wake vortex advisory system and Center-TRACON Automation System.
9. Relevance to this Research	An example of dozens of such Capacity Enhancement Plans prepared by the FAA Technical Center and local Airport Capacity Design Teams in the late 1980s and throughout the 1990s.

AIRFIELD CAPACITY CASE STUDIES
FAA Studies

18. Airport Capacity Benchmark Report 2004, Federal Aviation Administration and MITRE Corporation (2004)

KEY WORDS: Capacity benefits, aircraft delay, runways, hourly throughput, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To estimate capacity benchmarks for 35 of the nation's busiest airports.
2. Model and Metrics	**Model:** FAA Airfield Capacity Model (ACM) **Metrics:** 1. Hourly airport capacity calculated with the ACM 2. Hourly airport throughput calculated with actual traffic data and input from local air traffic specialist
3. Data Collected (Calibration/Validation)	**Data:** 1. Assumptions of new runways and technology improvements 2. Occurrence of weather conditions from ASPM 3. Hourly traffic data from ASPM **Calibration/Validation:** 1. Compared calculated capacity with published ATC facility rates 2. Compared calculated capacity with historical traffic data for arrivals and departures
4. Capacity Time Interval	Runway throughput and capacity was considered on an hourly basis for optimum, marginal, and IFR conditions.
5. Demand-capacity Comparison	Capacity benchmarks were developed as a range between ATC-facility published rates and capacity estimates calculated with the ACM. The capacity benchmarks were then compared with actual demand plotted on a graphical representation of a Pareto frontier.
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	Benchmark rates are airport-specific and heavily impacted by human factors. Traffic levels at a facility influence controller behavior and the need to reduce the amount of buffer over the absolute minimum allowable separations (e.g., buffers observed at ORD are below average due to the high traffic levels, resulting in higher throughput rates).
8. Consideration of NextGen Technologies	Several technical and procedural improvements were included in the capacity estimates including RNAV, CEFR, revised wake vortex separation standards for closely spaced parallel runways, and airspace redesigns.
9. Relevance to this Research	This study is an example of comparing actual throughputs with capacity estimates from various sources in the form Pareto frontiers of the 35 OEP Airports.

AIRFIELD CAPACITY CASE STUDIES
FAA Studies

19. Capacity Needs in the National Airspace System (FACT 2 Study, Federal Aviation Administration and MITRE Corporation (2007)

KEY WORDS: Capacity benefits, aircraft delay, future technologies, system planning, runways, NAS, hourly throughput, empirical capacity, service volume, analytical models.

TOPIC	DESCRIPTION
1. Purpose	To update previous capacity benchmark estimates for the OEP 35 airports plus 21 non-OEP airports to determine which airports and metropolitan areas have the greatest need for additional capacity.
2. Model and Metrics	**Model:** Enhanced Airfield Capacity Model (E-ACM) **Metrics:** (1) Hourly airport capacity, (2) Annual Service Volume (ASV) defined differently than in the existing AC 150/5060-5, (3) ratio of future demand to ASV, (4) scheduled arrival delay, (5) arrival queue delay, (6) departure queue delay, and (7) Local delay
3. Data Collected (Calibration/Validation)	**Data:** 1. Projected future enplanements and operations from the FAA's Terminal Area Forecast and MITRE CAASD's Future Air Traffic Estimator forecast 2. Assumptions of new or extended runways, new or revised ATC procedures, and airspace redesign improvements. **Calibration/Validation:** 1. Compared calculated capacity with published ATC facility (control tower or TRACON) rates 2. Compared calculated capacity with historical traffic data
4. Capacity Time Interval	Runway throughput capacity was considered on an hourly basis.
5. Demand-capacity Comparison	ASV was compared to forecast demand to assess capacity.
6. Estimating Aircraft Delay	1. ASV defined as the number of operations that would result in an average annual aircraft delay of 7 minutes per operation. 2. A NAS-wise simulation model developed by The MITRE Corporation was used to estimate the level of delay resulting from specific traffic levels.
7. Human Factors Considerations	Human factors were considered in facility-specific throughput estimates
8. Consideration of NextGen Technologies	Several technical and procedural improvements focused on Equivalent Visual Operations and Super Density Operations were considered in the capacity estimates.
9. Relevance to this Research	This study identifies airports needing additional capacity through ASV comparison with demand and consideration of aircraft delay. This study also makes note that an airport's runways are not always the limiting factor of capacity.

AIRFIELD CAPACITY CASE STUDIES

Academic Reports

20. 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

KEY WORDS: Capacity benefits, runways, empirical capacity

TOPIC	DESCRIPTION
1. Purpose	Demonstrates techniques for analyzing NASA Dynamic Runway Occupancy Measurement System (DROMS). Determined factors that affected Runway Occupancy Time (ROT) including: aircraft weight, velocity, air carrier, and meteorological conditions. Case study of ATL.
2. Model and Metrics	**Models:** 1. Vandevenee Model (Vandevenee, 1992) for inter-arrival separation distance 2. Estimated capacity equation **Data:** 1. Weather data (rainfall, wind speed, wind direction) 2. Aircraft Weight Class 3. Runway Used 4. Approach Speed 5. Runway Conditions (dry versus wet) 6. Runway Occupancy Time **Metrics:** 1. Momentum (Weight * Speed) vs. ROT 2. Effects of Aircraft Weight Class 3. Effects of Aircraft Category (speed) 4. Effects of Runways (e.g., location and type of exit ramps) 5. Effects of Headwind/Tailwind 6. Effects of Dry/Wet Runways 7. Effects of Day/Night
3. Data Collected (Calibration/Validation)	Mode S and Multilateration (1 sec update). 15 days of data. Analysis focused on peak-period operations.
4. Capacity Time Interval	15 minute
5. Demand-capacity Comparison	N/A
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	Provides analytical methods for analysis of track data to determine ROT that contributes to throughput capacity.

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

21. 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, 2006

KEY WORDS: Runways, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	Analytical; model to determine the optimal level of operations on a single runway used only for arrivals. Risk of a wake vortex encounter and the risk of simultaneous runway occupancy are considered explicitly. Case study of DTW.
2. Model and Metrics	**Model:** 1. Analytical Model based on empirical data **Data:** 1. Landing attempts per hour, i.e., flow rate 2. Landing-time Interval 3. Arrival rate to TRACON or, equivalently, the runway throughput rate, landing per hour 4. Probability of go around P{GA} **Metrics:** 1. Landings per Hour 2. Inter-arrival Time Statistics
3. Data Collected (Calibration/Validation)	Multilateration data 4 days of data. Analysis focused on peak-period operations.
4. Capacity Time Interval	15 minutes
5. Demand-capacity Comparison	N/A
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	Takes into account ATC Separation buffer and probability of arrival aircraft performing a Go Around.
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	Provides analytical methods for analysis of runway capacity

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

22. Byung, J.K., A. Trani, X. Gu, C. Zhong (2000) Computer Simulation Model for Airplane Landing Performance, Transportation Research Record 1562

KEY WORDS: Capacity benefits, runways, empirical capacity

TOPIC	DESCRIPTION
1. Purpose	Computer simulation model that predicts airplane landing performance on runways to locate high-speed exits is presented. A Monte Carlo simulation algorithm and empirical heuristics, derived from field observations, used to estimate landing-roll trajectories that can be programmed quickly in a personal computer. This approach is alternative to conventional methods for locating high-speed exits as well as a complement to more rigorous optimization of runway design. Case study of DCA, CLT, ATL.
2. Model and Metrics	**Model:** 1. Physics-based model **Data:** 1. A/C Type 2. Flare Speed 3. Touchdown Location 4. Average Deceleration 5. Landing Distance to 30 m/s **Metrics:** 6. Runway Occupancy Time
3. Data Collected (Calibration/Validation)	Visual surveillance of runway threshold data 4 days of data. Analysis focused on peak-period operations.
4. Capacity Time Interval	1 Hour
5. Demand-capacity Comparison	N/A
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	Provides computational methods for estimate of ROT

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

23. 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

KEY WORDS: Capacity benefits, runways, empirical capacity, analytical models.

TOPIC	DESCRIPTION
1. Purpose	Analysis of aircraft track data (DROMS) to determine runway arrival rates. Case study of MEM and DTW.
2. Model and Metrics	**Data:** 1. Arrival runway 2. Surface wind 3. Ceiling 4. Visibility 5. Weather data (rainfall …) 6. Aircraft Weight Category **Metrics:** 1. Landings per Hour 2. Inter-arrival Time Statistics
3. Data Collected (Calibration/Validation)	Multilateration data 2 days of data. VMC conditions Analysis focused on peak-period operations.
4. Capacity Time Interval	15 minutes
5. Demand-capacity Comparison	N/A
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	Provides analytical methods for analysis of runway capacity from aircraft track data

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

24. Amy Kim and Mark Hansen, Validation of Runway Capacity Models, 8th USA-Europe ATM Seminar, July, 2009; in Press, Transportation Research Record

KEY WORDS: Runways, hourly throughput

TOPIC	DESCRIPTION
1. Purpose	Develop methodology to validation runway capacity models and demonstrate it though application to two such models—Airport Capacity Model and Runway Simulator
2. Model and Metrics	**Models:** 1. Airport Capacity Model 2. Runway Simulator **Metrics:** 1. Arrival and departure throughput 2. Validation metrics related to predictive accuracy of the models a. Theil inequality coefficients b. Tobit model estimation results
3. Data Collected (Calibration/Validation)	Weather condition (IMC/VMC) from ASPM Arrival and departure counts Arrival and departure demand Runway configuration Arrival and departure mix
4. Capacity Time Interval	Hour
5. Demand-capacity Comparison	A statistical methodology that allows capacities to be inferred from data that includes both observations where throughput is demand limited and throughput is capacity limited
6. Estimating Aircraft Delay	N/A
7. Human Factors Considerations	N/A
8. Consideration of NextGen Technologies	N/A
9. Relevance to this Research	Provides analytical method for assessing the validity of any runway capacity model and showed that Runway Simulator is superior to ACM for the airports and time periods considered.

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

25. Hansen, Mark, Post-deployment Analysis of Capacity and Delay Impacts of an Airport Enhancement: Case of a New Runway at Detroit, Air Traffic Control Quarterly, 12, 4 (2004)

KEY WORDS: Capacity benefits, future technologies, runways, empirical capacity

TOPIC	DESCRIPTION
1. Purpose	Develop and demonstrate a new statistical method for estimating airport capacity and assessing the capacity and delay impacts of events such as opening a new runway or deployment of a new technology.
2. Model and Metrics	**Model:** 1. Censored regression model **Metrics:** 1. ASPM arrival and departure demand metrics on a quarter hour basis; these metrics reflect the number of flights that would arrive or depart in the absence of capacity constraints. 2. ASPM arrival and departure counts on a quarter hour basis; these metrics reflect the number of flights that actually arrive or depart. 3. Mean and standard deviation of arrival capacity and departure capacity under IMC and VMC, and before an after opening of runway 4L/22R. 4. Clearance rate, defined as average ratio of demand to count, by demand level.
3. Data Collected (Calibration/Validation)	1. ASPM 15-minute arrival and departure demand for first six months of 2001 and 2002 (before and after opening of new runway). 2. ASPM 15-minute arrival and departure count for first six months of 2001 and 2002 (before and after opening of new runway). 3. Visibility conditions (IMC/VMC) for each 15-minute period for first six months of 2001 and 2002 as reported by ASPM.
4. Capacity Time Interval	15-minutes
5. Demand-capacity Comparison	Yes. The statistical methodology was specifically developed to extract capacities from demand and count data, even though in many situations the demand is less than the capacity.
6. Estimating Aircraft Delay	Delay was estimated based on differences between demands and counts.
7. Human Factors Considerations	No.
8. Consideration of NextGen Technologies	It was argued that the same methodology could be applied to post-deployment assessment of such technologies.
9. Relevance to this Research	Provides method to estimate capacity from widely available demand and count data. A similar approach was used to validate capacity models, as described in **Validation of Capacity Models** above.

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

26. Pen-Chen Barru Liu, Mark Hansen, and Avijit Mukherjee, Scenario-based Air Traffic Flow Management: from Theory to Practice, Transportation Research B, 42, 7-8 (2008), pp. 685-702

KEY WORDS: Aircraft delay, system planning, runways, terminal airspace, NAS, empirical capacity

TOPIC	DESCRIPTION
1. Purpose	Develop airport capacity scenarios and scenario trees to support traffic flow management.
2. Model and Metrics	**Model:** The scenarios/scenario trees support various scenarios-based, stochastic optimization models to solve the single airport ground holding problem. These include both static stochastic and dynamic stochastic models. **Metrics:** Delay cost, a weighted sum of ground and airborne delay, as expected from the various models and realized from using the optimal strategies with realized capacity profiles.
3. Data Collected (Calibration/Validation)	Called airport acceptance rates for 15-minute periods for the entire year of 2003 for variety of major airports. Flight schedule data for representative days.
4. Capacity Time Interval	15 minutes
5. Demand-capacity Comparison	Yes. Scheduled demand derived from flight schedules. Managed demand derived from applying ground holding to scheduled demand
6. Estimating Aircraft Delay	Yes. Estimated by applying GDP rates to scheduled demand, and AAR's to managed demand.
7. Human Factors Considerations	May be reflected in weighting applied to airborne delay, which partly reflects controlled workload.
8. Consideration of NextGen Technologies	No.
9. Relevance to this Research	Develops *capacity scenarios*—representative time series of arrival capacities over the course of day for different airports. While originally developed for application in air traffic management, they have also been used in airport planning.

AIRFIELD CAPACITY CASE STUDIES
Academic Reports

27. A. Barnett, M. Ball, G. Donohue, M. Hansen, A. Odoni, T. Trani, Los Angeles International Airport North Airfield Safety Study, 2010

KEY WORDS: Capacity benefits, aircraft delay, runways, taxiways, hourly throughput, simulation

TOPIC	DESCRIPTION
1. Purpose	• Estimate level of future safety associated with each of several configurations of the LAX North Airfield • Provide useful information about the capacity implications of the various case studies
2. Model and Metrics	ExtendSim
3. Data Collected (Calibration/Validation)	• Data from real-time, human-in-the-loop simulations performed at NASA Ames Future Flight Central (FFC), including – Arrival and departure throughput – Taxi-in and taxi-out times – Voice communication analysis
4. Capacity Time Interval	Hour
5. Demand-capacity Comparison	• 2020 demand schedule used in FFC simulations, but with required inter-arrival times for arrivals. Departure throughput was therefore the primary basis for comparison among alternatives. • Used 2020 demand schedule to assess departure delays due to ADG VI aircraft blocking departure runway 24L under two alternative layouts.
6. Estimating Aircraft Delay	• Taxi-in and taxi-out times from FFC simulation compared across alternatives. • Departures delays on North Airfield simulated using ExtendSim and measured values for ADG VI crossing and taxi times.
7. Human Factors Considerations	Reflected in simulation results, since they are human-in-the-loop.
8. Consideration of NextGen Technologies	Not in relation to capacity. However, effects of RSL, ASDE-X, and AMASS considered in safety analysis.
9. Relevance to this Research	Shows that while safety considerations alone do not justify moving runways on North Airfield, capacity considerations may do so. Scope of study did not permit full analysis of capacity/delay issues, however.

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ACRP 03-17

Evaluating Airfield Capacity

Appendix 2 to Final Report: Review of Available Models

June 29, 2012

LeighFisher

in association with

Landrum & Brown

Wilbur Smith Associates

George Mason University

University of California, Berkeley

Presentation & Design, Inc.

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APPENDIX 2: REVIEW OF AVAILABLE MODELS

This appendix catalogs the range of available models relevant to estimating airfield capacity.

Key Factors for Determining Airport Capacity

An airport's capacity is a function of its physical facilities, the mix of aircraft using the airport, and its operating environment, which includes the airspace allocated to the airport and Air Traffic Control (ATC) procedures used to coordinate air traffic movement in a safe and expeditious manner. These operating environment factors affect the separation between successive aircraft performing similar activities or activities that must be coordinated in order to meet safety standards.

Runway length, width, pavement strength and orientation determine whether a runway is usable by a particular aircraft for landing or take-off. The runway must be long enough for an aircraft to accelerate to take-off speed or slow down enough to exit the runway. It must be wide enough to accommodate the width of the landing gear and the speed of a crosswind which may blow an aircraft off the runway centerline. Pavement must be strong enough to hold the aircraft. The runway's orientation to the wind will affect runway length and width requirements. It is assumed that all of the models we reviewed take the foregoing runway length, width, pavement strength, and orientation into account.

Twenty-one key factors for determining airport capacity were identified as part of this study. These factors affect airport capacity, and the possibility to reflect them as assumptions or variables in capacity modeling techniques may determine the choice of model used to calculate capacity. The twenty-one factors are described below.

The following physical facility (Geometry) factors affect airport capacity:

1. **Runway Exit Design** – Exits that have a shallow angle to the runway centerline will allow an aircraft to exit the runway at a higher speed than a more acutely angled exit. Usually an aircraft will need to stop on the runway to use a ninety degree or reverse angle exit. Having a landing aircraft exit the runway at a higher speed reduces aircraft time on the runway, allowing the runway to be used another aircraft more quickly.

2. **Runway Entrance Design/Multiple Entrance Taxiways** – Standard IFR separation values are smaller if two successive departures turn different directions during climb-out of the airport. Having more than one entrance taxiway to a runway may increase runway capacity, especially if the taxiway system at the airport has insufficient flexibility for air traffic controllers to optimize the sequence of departing aircraft so that successive departing aircraft always turn in different directions. A secondary entrance taxiway may allow a departing aircraft to use only a portion of a runway that does not intersect with another runway rather than use the full length of the runway. Using an

"intersection departure" may eliminate the need to coordinate the operation of two runways.

3. **Departure Staging and Sequencing Taxiways or Areas** – Taxiways provide the link between runways and aircraft parking areas (or gates) for arriving aircraft and gates and the runway for departing aircraft. Aircraft remain on the taxiways while delayed because of another aircraft is using the runway or a gate is occupied. A taxiway holding bay provides a staging area for aircraft that must wait because of a capacity constraint in the airspace. This aircraft would otherwise block access to the runway by another aircraft that does not face the same constraint. Availability of departure headings (e.g., having more than one flight path from a departure runway) may allow an air traffic controller to reduce the separation between successive aircraft using the runway.

4. **Runway Crossings** – Aircraft taxiing across an active runway take away time from the runway's primary purpose of providing a space for landing and departing aircraft. In addition, these aircraft also divert air traffic control resources from the task of controlling landing and departing aircraft.

5. **Parallel Taxiway** – A parallel taxiway allows a departing aircraft to reach a runway entrance without taxiing on the runway or keeps an arriving aircraft from having to back taxi on the runway if rolls past the last runway exit.

Aircraft mix and scheduling factors such as the following also affect capacity:

6. **Aircraft fleet mix**– Aircraft fleet mix includes size, engine power, and weight of aircraft. Generally larger/heavier aircraft need longer runways unless they have sufficiently powerful engines to increase acceleration rates. In particular, a fleet mix with many heavy and B757 aircraft may have a lower capacity because of increased spacing required behind these aircraft.

7. **Daily Distribution of Aircraft Activity** – Scheduling patterns influence airport capacity. At small airports, traffic tends to peak in the morning and at night, sometimes influences by weather or air traffic. 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 airport capacity because a comparatively large number of aircraft are attempting the same activity nearly simultaneously. Long distance flights also affect utilization of airport capacity since airlines schedule flights when passengers demand them. Most passengers generally do not want flights that arrive and depart in the middle of the night.

Aircraft performance factors such as the following also affect capacity:

8. **Aircraft Avionics Equipage** – The onboard flight navigation instruments or avionics available to the pilot influence the types of arriving and departing procedures that the pilots can use to fly through the local airspace surrounding

the airport and for the entire flight. The FAA's Next-Gen program creates air route opportunities, and arrival and departure procedures that are available only if the aircraft has the appropriate on-board flight navigation equipment. These avionics create new airspace capacity, which in some cases increases airport runway capacity.

9. **Pavement Conditions and Braking Action** – These factors affect runway capacity by extending runway occupancy times and changing exit taxiway usage. Grooved pavements improve aircraft stopping performance versus smooth pavements. Wet or icy pavements can degrade aircraft stopping performance, increasing landing roll distances and times, or increase departure runway length needs, which may affect departure runway choice.

10. **Random Variability** – many aspects of aircraft and human performance can be specified as random variables in an airfield capacity model. For example, the final approach speeds of aircraft depend on aircraft weight and wind conditions, which vary among aircraft and over time. In addition, controllers build in a buffer to aircraft operations to reduce the probability of operational error recognizing that factors such as wins, aircraft weight, and pilot technique can affect the separations between airplanes. Models try to capture the effect of such random variability through the use of random variables representing aircraft human performance and statistical buffers are presenting the accuracy with which aircraft can be delivered to the final approach fix.

Runway use and ATC procedures factors such as the following also affect airfield capacity:

11. **Applicability and acceptance of visual flight rules and visual approaches** – Airport runway capacity is usually higher during visual flight rules where pilots accept responsibility for self separation from other air traffic through "see and avoid" techniques. Under instrument flight rules, air traffic controllers separate aircraft by applying standard separation distances. Due to the variability of weather conditions, controllers will add an additional separation buffer to assure that minimum separation distance standards will not be violated. Pilot acceptance of visual flight rules also depends on the pilot's level of comfort with the English language and using voice communications to understand the location of other air traffic.

12. **Wake Turbulence** – Aircraft separations standards vary depending upon the weight or wake/turbulence classification for each of the pair of aircraft involved. Wake turbulence is generated by the aircraft's wings and is generally more violent from larger and heavier aircraft. The FAA classifies aircraft into four groups based upon weight or their wake generating characteristics.

13. **Weather** – wind speed and direction determine aircraft speed over the ground during flight. Wind speed variability (gusts) may cause a pilot to increase

speed. Higher approach or departure speeds generally increase runway length needs. Weather also may determine pavement conditions as described below.

14. **Multiple Approach Technology** – Multiple Approach Airspace design has extended final approach corridors, which tends to magnify the negative effects of aircraft speed variations on individual runway acceptance rates (a similar effect occurs on triple parallel departure runways).

15. **Runway-specific fleet mix assignment** – An airport runway can be limited by the types of aircraft which is able to use it. Factors such as design group, runway length, or noise restrictions may cause the fleet mix of the aircraft which use a particular runway to differ from the overall airport fleet mix. Limitations on aircraft types able to use a particular runway cause negative impacts on airport capacity.

Human factors such as the following also affect airfield capacity:

16. **Human Factors (Controller Workload)** – Some combinations of intersecting and parallel runways create additional controller workload by either increasing the number of tasks that a controller must conduct, or by increasing the number of simultaneous aircraft the controller must track.

17. **Human Factors (Air-Ground Communications)** – While there has been considerable study of human factors in radar control, less quantified research is available for airport control tower environments, where a playback capability does not routinely exist. The human interaction between pilot and controller is a critical factor in determining runway capacity, as time is required for the controller to attain situational awareness, understand communications, issue communications and verify that communications were understood.

18. **Random variability** –human performance factors can be represented as random variables in airfield capacity models. For example, some models at a buffer to aircraft separations to reflect the ability of controllers to communicate with pilots and vector aircraft to the final approach fix.

Airspace factors such as the following also affect airfield capacity:

19. **Departure Fix/Heading Restrictions** – An aircraft flight traverses from a departure runway through a series of waypoints or fixes to an arrival runway. These waypoints are generally points 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 or heading, air traffic controllers may restrict the flow of traffic from an airport by assigning a minimum distance or time between successive flights.

20. **Neighboring Airports** – An airport 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 approach and departure paths cross or must be shared. When this occurs, air traffic controllers must coordinate air traffic between the two airports. Coordinating air traffic usually results in a substantial loss of capacity.

21. **Missed approach and balked landing procedures** – Various procedures for coordinating arrivals and departures on single and multiple runway geometry airfields call for various levels of coordination of departures with a potential missed approach or balked landing. Other airspace issues also affect airfield capacity. Every airport has a unique context within a regional air traffic management system. While there are many common factors that cover a large number of airports, there are other rarer factors that may or may not be included in a handbook on airport capacity.

All of these factors have variability since they depend on or are affected by natural factors such as wind and weather or human factors. Various models represent these factors using random variability**.**

We evaluated a wide range of models to determine whether each model considered these 21 different factors in their computations of aircraft throughput through various portions of the airport/airspace system. The list of models we evaluated includes both delay and capacity models since many delay models instantaneously compute many capacity determining variables when computing delays. The results of this evaluation are shown for each model in the following sections. The models are summarized in Table 2. The summaries of the models follow Table 2.

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Table 2
ACRP PROJECT 03-17—EVALUATING AIRFIELD CAPACITY
Index to Available Models – Capacity Factor/Issue
Airfield Capacity Models

		Geometry					Airline Factors		Aircraft Performance			Runway Use and ATC procedures					Human Factors			Airspace Factors		
	Model	Runway exits (arrival runway occupancy times)	Runway entrance design/Multiple entrance taxiways	Departure staging and sequencing	Runway crossings	Parallel taxiway	Fleet Mix	Daily Distribution of Aircraft Activity	Aircraft avionics equipage	Pavement conditions/braking action	Random variability	Visual flight rules/visual approaches	Wake Vortex	Weather	Multiple approach technology	Runway-specific fleet mix assignment	Controller workload	Voice communications	Random variability	Departure fix restrictions	Neighboring airports	Missed approaches
	Spreadsheets and Table lookups																					
1	FAA Airport Design	🟨	🟨	🟥	🟨	🟨	🟨	🟥	🟥	🟥	🟥	🟨	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
2	Wilbur Smith	🟨	🟥	🟥	🟥	🟨	🟨	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
3	AC 150/5060-6	🟨	🟨	🟨	🟨	🟨	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟨
	Analytical models																					
4	SADM	🟥	🟥	🟥	🟥	🟥	🟥	🟨	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
5	ACM	🟩	🟨	🟨	🟨	🟨	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩
6	LMI Runway	🟩	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟨	🟨	🟩
7	Boeing Constraints	🟩	🟥	🟥	🟩	🟨	🟩	🟥	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟩	🟩	🟩	🟩
8	RUNCAP	🟩	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟩	🟨	🟥	🟨
	Simulation models																					
9	REDIM	🟩	🟥	🟥	🟥	🟨	🟩	🟥	🟥	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟥	🟥	🟨	🟥	🟥	🟥
10	FLAPS	🟩	🟩	🟨	🟨	🟨	🟩	🟥	🟨	🟥	🟩	🟩	🟩	🟩	🟨	🟥	🟥	🟥	🟩	🟨	🟥	🟨
11	GATESIM	🟩	🟩	🟨	🟩	🟨	🟩	🟨	🟥	🟥	🟩	🟩	🟩	🟩	🟨	🟨	🟥	🟥	🟨	🟥	🟥	🟥
12	AIRSIM	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨
13	RDSIM	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨
14	ADSIM	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨
15	Runway Simulator	🟩	🟨	🟨	🟨	🟨	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟩
16	TAAM	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟥	🟨	🟨	🟨	🟥
17	SIMMOD	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟥	🟩	🟩	🟩	🟥

🟩 Model fully addresses capacity factor	🟨 Model partially or indirectly addresses capacity factor	🟥 Model does not address capacity factor

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AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SPREADSHEETS AND TABLE LOOKUPS

1. FAA AIRPORT DESIGN PROGRAM MODEL

Model Summary

The FAA Airport Design Computer Program model, introduced and described within FAA AC 150/5300-13, *Airport Design*, Appendix 11, generally addresses six (6) planning areas of focus within that circular, including:

1. Width and wingtip clearance standard dimensions for runway, taxiway, taxilane, and associated facilities;
2. Runway design, including recommended runway lengths;
3. Runway wind coverage analysis, including wind roses;
4. Taxiway design, including exit, intersection, and curve configurations;
5. Airport capacity and delay for long range planning; and
6. Declared distance lengths.

Specific to airport capacity, the Airport Design Computer Program utilizes methodologies and algorithms detailed in FAA AC 150/5060-5, *Airport Capacity and Delay*, to provide the standards for calculating airport capacity and delay. Specifically, the program utilizes the assumptions and performs the calculations specified in AC 150/5060-5, Chapter 2, *Preliminary Procedures*, to generate generalized assessments of Annual Service Volumes (ASV) for analyzed airports.

Level of Modeling Sophistication and Model Applications

The Airport Design Computer Program model entails minimal time and effort to produce ASV capacity estimates. It requires only four individual inputs and an appropriate interpretation of the model results. Its simplicity lends itself well to analysis of General Aviation airports which, by their nature, are extremely diverse in activity levels, types, and peaking characteristics, thereby requiring a broader basis of modeling analysis.

Model Specifications

The most recent Airport Design Computer Program model (Release 4.2) was developed and integrated into FAA AC 150/5300-13 in 2000. The model is a Windows DOS application, requiring individual input elements through an interactive user interface and output of a text file, as well as other elements, depending on the use of individual program tasks.

Inputs and Data Availability

The Airport Design Computer Program model requires four (4) individual input elements:

1. Percent of airplanes over 12,500 lbs but not over 300,000 lbs with respect to the total number of aircraft operations;

2. Percent of airplanes over 300,000 lbs with respect to the total number of aircraft operations;

3. The targeted level of annual operations (the demand); and

4. The predominate operations (either air carrier or general aviation).

Additional data required is the classification of the airfield configuration in order to interpret the program output. Data for all input elements is typically readily available or determinable for nearly all airports.

Outputs

The Airport Design model lists the runway-use configurations in rank order of capacity and least delay. The outputs of the model are unusual in that there are up to 19 different types of output, each uniquely based on a particular airfield/runway configuration (i.e., single runway, dual parallel runways, open-V runway configuration, etc.). For each runway configuration, the model produces the following capacity outputs based on the inputs:

- Maximum operations per hour (for both VFR and IFR operations)

- Annual Service Volume (ASV)

- Ratio of annual demand to ASV

- Average delay per aircraft (in minutes)

- Total minutes of annual delay (in minutes)

Model Limitations

The Airport Design Computer Program model is restricted to the assumptions and methodologies of AC 150/5060-5, Chapter 2. Specifically, the Airport Design Computer Program model is limited to predefined runway configurations and operating strategies, and does not include the assignment of specific fleet mixes, operational types and patterns, and seasonal peaking characteristics, nor does it include the modification/adjustment of the previous assumptions. The model does not explicitly factor in broader operational issues related to airfield geometry and airspace structure, and does not explicitly include the impact of taxiway congestion, parking availability, runway crossings, and departure queue management on capacity.

Table 2.2-1
FAA AIRPORT DESIGN PROGRAM MODEL

Capacity Factor/Issue	A/P Design	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Existence of “ample” exits included within model assumptions.
2. Runaway entrances design/ multiple entrance taxiways		Existence of “ample” entrances included within model assumptions.
3. Departure staging and sequencing		Not directly considered, although adequacy implied within assumptions.
4. Runway crossings		It is assumed that there are no operational problems with respect to runway crossings.
5. Parallel taxiway		Existence of full length parallel taxiways are included within model assumptions.
Airline Factors		
6. Fleet mix		Only considered in terms of aircraft weight and prevailing aircraft operations types.
7. Daily distribution of aircraft activity		Not directly considered.
Aircraft Performance		
8. Aircraft avionics equipage		Not directly considered, although implied within assumptions.
9. Pavement conditions/braking action		Not directly considered.
10. Random variability		Not directly considered.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Assumptions include 10% IFR operations.
12. Wake turbulence		Not directly considered, although implied within assumptions.
13. Weather		Assumptions include 10% IMC.
14. Multiple approach technology		Not directly considered, although implied within assumptions and runway configurations.
15. Runway-specific fleet mix assignment		Not directly considered, although implied within assumptions.

Table 2.2-1 *(page 2 of 2)*
FAA AIRPORT DESIGN PROGRAM MODEL

Capacity Factor/Issue	A/P Design	Comments/Questions
Human Factors		
16. Controller workload		Not directly considered, although implied within assumptions.
17. Voice communications		Not directly considered, although implied within assumptions.
18. Random variability		Not directly considered.
Airspace Factors		
19. Departure fix restrictions		Not directly considered, although implied within assumptions.
20. Neighboring airports		Not considered.
21. Missed approaches		Not directly considered, although implied within assumptions.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SPREADSHEETS AND TABLE LOOKUPS

2. WILBUR SMITH ASSOCIATES SYSTEM CAPACITY SPREADSHEET MODEL

Model Summary

The WSA system capacity spreadsheet model calculates the annual service volume (ASV) for airports that do not have the full range of facilities and services assumed in the FAA's calculations for long range planning purposes. These assumptions include the presence of a "full-length parallel taxiway, ample runway entrance/exit taxiways, and no taxiway crossing problems." They also assume that the airport has at least one runway with an ILS and air traffic control, as well as a radar environment. The WSA spreadsheet model takes the runway use configurations from the Advisory Circular and allows for adjustments based on the availability of specific items such as parallel taxiway, runway surface, air traffic control tower, precision approach, and fleet mix.

Level of Modeling Sophistication and Model Applications

The WSA spreadsheet model is simplistic and requires that each airport's geometry, annual operations estimates, facilities and services be evaluated in order to determine the appropriate inputs. The model is most useful to support high level system wide planning decisions regarding potential airfield capacity issues as part of system planning projects.

Model Specifications

The WSA spreadsheet model was developed in 2003 for use in system plans. It is an Excel-based spreadsheet model.

Inputs and Data Availability

The WSA spreadsheet model requires a number of widely available inputs for each airport in the system that is being analyzed. Model inputs include operations, fleet mix index, runway and taxiway configuration and surface type, runway use diagram from the AC, air traffic control tower availability, and approach type.

Outputs

The output of the model is an ASV for each system airport.

Model Limitations

The WSA spreadsheet model is limited to use for small airports that are non-towered and for which a standard AC methodology is not appropriate.

Table 2.2-2
SUMMARY OF THE WSA SPREADSHEET MODELING APPROACHES

Capacity Factor/Issue	WSA model	Comments/Questions
Geometry		
1. Runway exits	🟨	Acknowledges based on diagrams.
2. Runaway entrance design	🟥	
3. Departure staging and sequencing	🟥	
4. Runway crossings	🟥	
5. Parallel taxiway	🟨	Acknowledges based on diagrams.
Airline Factors		
6. Fleet mix	🟨	Based on percent of operations by type.
7. Daily distribution of aircraft activity	🟥	Not considered.
Aircraft Performance		
8. Aircraft avionics equipage	🟥	
9. Pavement conditions/braking action	🟥	
10. Random variability	🟥	
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	Considers type of approach.
12. Wake turbulence	🟥	
13. Weather	🟥	
14. Multiple approach technology	🟥	
15. Runway-specific fleet mix assignment	🟥	
Human Factors		
16. Controller workload	🟥	
17. Voice communications	🟥	
18. Random variability	🟥	
Airspace Factors		
19. Departure fix restrictions	🟥	
20. Neighboring airports	🟥	
21. Missed approaches	🟥	

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

**AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SPREADSHEETS AND TABLE LOOKUPS**

3. FAA DRAFT ADVISORY CIRCULAR, *AIRPORT CAPACITY AND DELAY*, 150/5060-6

Model Summary

The draft of the new FAA Advisory Circular (AC) 150/5060-6, *Airport Capacity and Delay*, represents a new approach to capacity and delay analysis for all categories of airports. The draft AC presents simple techniques focused on use at smaller commercial and general aviation airports not in need of detailed capacity analysis. There are “practical rules of thumb” and two analytical models included in the AC.

Level of Modeling Sophistication and Model Applications

The “practical rules of thumb” presented in the draft AC are summarized in eight rules that describe various runway configurations. The “rules of thumb” provide estimates of the maximum throughput capacities in terms of numbers of arrivals and departures per hour. These are separated into VFR and IFR conditions and do not consider delay. These eight “rules of thumb” include:

In addition to the “rules of thumb” for various runway configurations, there are also two analytical spreadsheet models included in the draft AC. These are the Expected Value Model and Annual Capacity Model. In addition, the AC references the Annual Delay Model but notes that contact with an FAA regional airport planner is needed to obtain a copy.

The Expected Value Model estimates maximum hourly throughput capacity but is more precise than the “rules of thumb” as it considers the fleet mix of the airport. It estimates hourly capacities for arrival-only runways and departure-only runways. The AC utilizes10 fleet mixes to estimate maximum throughput capacities at 10 airport types for both the Expected Value Model and the Annual Capacity Model.

The Annual Capacity Model, also an analytical spreadsheet model, is complimentary to the Expected Value Model and is used to estimate the maximum annual throughput capacity of an airport’s runway system.

Model Specifications

The draft AC notes the availability of three analytical spreadsheet models, but does not provide the specifications at this time.

Inputs and Data Availability

The draft AC identifies the following as elements of the Expected Value Model:

1. Fleet mix of airport
2. Runway configuration

It uses the aircraft fleet mix and a matrix format to determine the probability of various lead-trail combinations of aircraft classes using built-in aircraft separations.

For the Annual Capacity Model, the hourly throughput estimates from the Expected Value Model are used. In addition, airfield hub type, number of "useful hours," full capacity" of runway use, and seasonal demand are required inputs.

Outputs

The outputs of the Expected Value Model are maximum hourly throughput capacities. The arrival capacity for VFR, IFR with a 2.5 NM minimum, and IFR with a 3.0 NM minimum are provided. The VFR and IFR departure capacity is also provided.

For the Annual Capacity Model, the output shows the airport/fleet mix type with local demand factors applied to produce maximum annual capacity for VFR and IFR conditions in other columns. The last column presents the maximum estimated annual total capacity.

Model Limitations

The draft AC is specific in noting that the models described are useful for conditions where airport capacity is not likely to be a significant issue and a high level of accuracy is not required. The two analytical spreadsheet models do not provide any quantifiable levels of delay that relate to the maximum throughput capacities that are provided as output from the models. The draft AC provides summaries of other FAA simulation models that may be needed for more complex modeling. It does not appear from the information contained in the draft AC that the following can be addressed through the models:

1. Percent touch and go's
2. Taxiways other than full length
3. Airspace limitations
4. Differences in runway instrumentation or ATC availability

Table 2.2-3
SUMMARY OF THE ADVISORY CIRCULOR MODELING APPROACHES

Capacity Factor/Issue	AC	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Existence of “ample” exits included within model assumptions.
2. Runway entrances (departure runway occupancy times)		Existence of “ample” entrances included within model assumptions.
3. Departure staging and sequencing		Indirectly considered and reasonable adequacy implied within assumptions.
4. Runway crossings		Different runway layouts are available to choose from.
5. Parallel taxiway		Existence of full length parallel taxiways are included within model assumptions.
Airline Factors		
6. Fleet mix		Several options are provided to choose from.
7. Daily distribution of aircraft activity		Not directly considered.
Aircraft Performance		
8. Aircraft avionics equipage		Not directly considered, although implied within assumptions.
9. Pavement conditions/braking action		Not directly considered.
10. Random variability		Not directly considered.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Calculated in capacities.
12. Wake turbulence		Calculated in capacities.
13. Weather		Calculates separate VFR and IFR conditions.
14. Multiple approach technology		Not directly considered, although implied within assumptions and runway configurations.
15. Runway-specific fleet mix assignment		Not directly considered, although implied within assumptions.

Table 2.2-3 *(page 2 of 2)*
SUMMARY OF THE ADVISORY CIRCULATOR MODELING APPROACHES

Capacity Factor/Issue	ACM	Comments/Questions
Human Factors		
16. Controller workload		Not directly considered, although implied within assumptions.
17. Voice communications		Not directly considered, although implied within assumptions.
18. Random variability		Not directly considered.
Airspace Factors		
Departure fix restrictions		Not directly considered, although implied within assumptions.
Neighboring airports		Not considered.
Missed approaches		Partially considered and implied within assumptions.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
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4. LANDRUM & BROWN SIMPLIFIED AIRPORT DELAY MODEL (SADM)

Model Summary

The simplified airport delay model is a time-slice linked queuing model that coordinates the operation of arrival and departure runway models. It operates on a five-minute time slice comparing arrival demand to arrival runway capacity and departure demand to departure runway capacity. It computes runway throughput, queued arriving and departing aircraft, and total arrival and departure delays.

The model operates with four linked spreadsheets: a demand model that represents the volume of arriving and departing aircraft by five minute increments, an arrival runway queue model, a departure runway queue model and demand/capacity analysis model. The demand/capacity analysis model selects the capacity mode for the runway system, choosing between three modes of operation – (arrival preference, departure preference and balanced flow). Runway capacity values are computed externally to the model.

Level of Modeling Sophistication and Model Applications

SADM operates very quickly allowing testing of a wide range of capacity management and demand flow alternatives. Demand consists of a flow of arriving and departing aircraft by five minute increments. Capacity is also provided in five minute increments. The model compares demand and capacity and computes the flow of aircraft through the model and the demand delayed to the following five minute period. Multiple weather conditions, configurations or airfield improvement options are reflected in model inputs and are not computed by the model.

Model Specifications

SADM was developed by Landrum & Brown in the late 1990s. The model consists of four linked MS Excel spreadsheets.

Inputs and Data Availability

Input data is usually derived from OAG flight schedules or FAA ASPM data system. The model relies on airport capacity estimates computed through other means outside of the model itself.

Outputs

Outputs are a series of tables within MS Excel tables and charts that describe delays and aircraft queues and flows by various time increments.

Model Limitations – Delay Model Only

Table 2.2-4
SUMMARY OF SADM MODELING APPROACHES

Capacity Factor/Issue	SADM	Comments/Questions
Geometry		
1. Runway exits		Not considered
2. Runaway entrances design		Not considered
3. Departure staging and sequencing		Not considered
4. Runway crossings		Not considered
5. Parallel taxiway		Not considered
Airline Factors		
6. Fleet mix		Not considered
7. Daily distribution of aircraft activity		Reflected in volumes shown on input flight activity flows
Aircraft Performance		
8. Aircraft avionics equipage		Not considered
9. Pavement conditions/braking action		Not considered
10. Random variability		Not considered
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Not considered
12. Wake turbulence		Not considered
13. Weather		Not considered
14. Multiple approach technology		Not considered
15. Runway-specific fleet mix assignment		Not considered
Human Factors		
16. Controller workload		Not considered
17. Voice communications		Not considered
18. Random variability		Not considered
Airspace Factors		
19. Departure fix restrictions		Not considered
20. Neighboring airports		Not considered
21. Missed approaches		Not considered

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
ANALYTICAL MODELS

5. FAA AIRFIELD CAPACITY MODEL (ACM)

Model Summary

The ACM calculates the maximum hourly throughput capacity of an airfield configuration. The model uses input parameters to determine the minimum allowable time separation (intervals) between aircraft using the runways at an airport, and then averages the intervals to estimate hourly runway capacity.

Level of Modeling Sophistication and Model Applications

The ACM is an analytical model requiring minimal time and effort to produce capacity estimates. The model is most useful to support high level policy and planning decisions when used to estimate how typical changes at an airport (i.e., additional or reconfigured runways, changes in fleet mix or ATC rules) would impact capacity.

Model Specifications

The ACM was developed in the early 1970's for FAA by Peat, Marwick, Mitchell & Co. (now LeighFisher) and subsequently updated in the earl 1980's by the MITRE Corporation. The model is written in FORTRAN, using a single text file as input and outputting a text file. The original model had no graphical interface; however subsequent model updates have allowed interactive user input.

Inputs and Data Availability

The ACM requires a limited number of widely available inputs. Model inputs include runway configuration and operating strategy, fleet mix, percent arrivals, aircraft approach speeds, runway occupancy times, weather conditions, and ATC separation requirements.

Outputs

The outputs of the model are arrival-priority capacity and departure-priority capacity. These capacities, which can be plotted as a Pareto frontier, can be used to calculate an hourly airport capacity. These capacities are also direct inputs to the Annual Delay Model or other delay estimation tools.

Model Limitations

The ACM is limited to predefined runway configurations and operating strategies, and does not include some more complex runway geometries or the assignment of runway-specific fleet mixes (these complexities must be manually calculated and represented by the user through post-processing results of component analyses). The ACM is a runway-centric model in that it does not explicitly factor in broader operational issues related to airfield geometry and airspace structure. The model does not explicitly include the impact of taxiway congestion, gate availability, runway crossings, and departure queue management on capacity. Also, the ACM does not explicitly consider airspace factors such as noise abatement procedures or departure fix restrictions. However, these complexities can be reflected by constraining certain inputs.

Table 2.2-5
SUMMARY OF THE ACM MODELING APPROACHES

Capacity Factor/Issue	ACM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Can input either exit locations or average AROTS.
2. Runaway entrances design/ multiple entrance taxiways		DROTS are an input.
3. Departure staging and sequencing		Only indirectly through constrained departure-departure separation.
4. Runway crossings		Only indirectly through reducing number of minutes in the hour available for runway operations.
5. Parallel taxiway		Only indirectly through AROTS and DROTS.
Airline Factors		
6. Fleet mix		Up to four aircraft weight-speed classes can be considered.
7. Daily distribution of aircraft activity		Not considered except through aircraft fleet mix.
Aircraft Performance		
8. Aircraft avionics equipage		Only indirectly through buffers and aircraft separations.
9. Pavement conditions/braking action		Only indirectly through aircraft mix that can use runway and AROTS.
10. Random variability		User can specify standard deviation of various aircraft operating times.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Represented through arrival-arival separations and lengths of common approach path.
12. Wake turbulence		Represented through wake turbulence operations and runway dependencies.
13. Weather		Represented through aircraft separations and runway dependencies.
14. Multiple approach technology		Certain multiple configurations specifically modeled; others must be built up manually through analysis of components.
15. Runway-specific fleet mix assignment		Can be input into model but overall “airfield mix” must be enforced manually.

Table 2.2-5 *(page 2 of 2)*
SUMMARY OF THE ACM MODELING APPROACHES

Capacity Factor/Issue	ACM	Comments/Questions
Human Factors		
16. Controller workload	■ (yellow)	Not considered except through constrained aircraft separations.
17. Voice communications	■ (yellow)	Not considered except through constrained aircraft separations.
18. Random variability	■ (yellow)	Buffer calculated as function of user-specified standard deviation and probability of violation.
Airspace Factors		
19. Departure fix restrictions	■ (yellow)	Indirectly through constrained departure-departure separations.
20. Neighboring airports	■ (yellow)	Not considered except through constrained aircraft separations.
21. Missed approaches	■ (green)	Considered through hardwired test of need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation if landing aircraft not clear of clouds 2 nautical miles out from threshold.

■ (green) Model fully addresses capacity factor

■ (yellow) Model partially or indirectly addresses capacity factor

■ (red) Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
ANALYTICAL MODELS

6. LMI RUNWAY CAPACITY MODEL

Model Summary

The LMI Runway Capacity Model, like the ACM, calculates the maximum hourly throughput capacity of an airfield configuration. In the LMI model, the approach speeds, the runway occupancy times, and the delay in communication time between airport controllers and pilots are all incorporated into the model as random variables. Also similar to the ACM, the LMI model determines four points on the Pareto frontier: (1) the "all arrivals" point, (2) the "freely inserted departures" point, (3) the "alternating arrivals and departures" point, and (4) the "all departures" point.

Level of Modeling Sophistication and Model Applications

The LMI Runway Capacity Model, like the ACM, is an analytical probability model requiring minimal time and effort to produce capacity estimates. The model is most useful to support high level policy and planning decisions.

Model Specifications

The LMI Capacity Model was written in Pascal and C. The model uses a GUI, in the form of a spreadsheet that the user can use to enter input parameters and display the capacity curve.

Inputs and Data Availability

Inputs include: the mix and number of aircraft types, length of common approach and departure paths, mean and standard deviation of approach and departure speeds, mean and standard deviation of arrival and departure runway occupancy times, the minimum in-trail separations, standard deviation of wind speed, standard deviation of the position of each aircraft, and mean and standard deviation of the communication time delay.

Outputs

The LMI Model estimates the four capacity points for Pareto frontier, which can be used to calculate an hourly airport capacity. Capacity is defined as the number of operations that can occur on a runway with 95% confidence in the presence of continuous demand, which is different from the ACM definition of maximum throughput capacity. The model also assumes that the rule that two landing aircraft should not be on the same runway at the same time should be maintained 98.7% of the time. These capacities are also direct inputs to the LMI aircraft delay model.

Model Limitations

The LMI Model does not explicitly include the impact of taxiway congestion, gate availability, runway crossings, and departure queue management on capacity. In addition, it does not explicitly consider airspace factors such as noise abatement procedures or departure fix restrictions. However, as is the case for the ACM, these complexities can be reflected by constraining certain inputs.

Table 2.2-6
SUMMARY OF THE LMI MODELING APPROACHES

Capacity Factor/Issue	LMI	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Mean and standard deviation of AROTs are input as random variables.
2. Runaway entrances design/ multiple entrance taxiways		Mean and standard deviation of DROTs are input as random variables.
3. Departure staging and sequencing		Only indirectly through constrained departure-departure separations.
4. Runway crossings		Only indirectly through constraining other inputs.
5. Parallel taxiway		Only indirectly through AROTs and DROTs.
Airline Factors		
6. Fleet mix		User specified fraction of operating aircraft that are of each type.
7. Daily distribution of aircraft activity		Not considered except through aircraft fleet mix.
Aircraft Performance		
8. Aircraft avionics equipage		Only indirectly through means and standard deviations of aircraft performance characteristics.
9. Pavement conditions/braking action		Only indirectly through aircraft mix that can use runway and AROTS.
10. Random variability		User can specify standard deviations of aircraft speeds, runway occupancy times, aircraft position, winds, and communication times.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Represented through arrival-arival separations and lengths of common approach path.
12. Wake turbulence		Represented through wake turbulence operations and runway dependencies.
13. Weather		Represented through aircraft separations and runway dependencies.
14. Multiple approach technology		Pareto frontiers are built up manually for multiple runway configurations.
15. Runway-specific fleet mix assignment		Can be input into model but overall “airfield mix” must be enforced manually.

Table 2.2-6 *(page 2 of 2)*
SUMMARY OF THE LMI MODELING APPROACHES

Capacity Factor/Issue	LMI	Comments/Questions
Human Factors		
16. Controller workload		Considered through standard deviation of communication times and TRACON delivery inefficiency parameter.
17. Voice communications		Considered through mean and standard deviation of communication time delay.
18. Random variability		Considered through mean and standard deviation of communication time delay.
Airspace Factors		
19. Departure fix restrictions		Indirectly through constrained departure-departure separations.
20. Neighboring airports		Not considered except through constrained aircraft separations.
21. Missed approaches		Considered through need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
ANALYTICAL MODELS

7. BOEING AIRPORT CAPACITY CONSTRAINTS MODEL

Model Summary

The Boeing Airport Capacity Constraints Model consists of (1) a single runway constraints model and (2) a runway interaction and airfield constraints model. The single runway constraints model is used to evaluate the hourly arrival, departure, and mixed operations rates for a single runway at each airport for three weather conditions. For the runway interaction and airfield constraints model, constraints are defined that reduce the theoretical hourly capacity for each airport.

Level of Modeling Sophistication and Model Applications

The Boeing Airport Capacity Constraints Model is a hybrid simulation-regression model that was developed to evaluate the reduction in theoretical hourly airport capacity at a large number of airports due to constraints caused by airfield configuration or operational procedures and then quickly evaluate a range of enhancement alternatives.

Model Specifications

The single runway capacity constraints model is a fast-time Monte Carlo simulation that was developed in 1990. The constraints to the theoretical capacity are defined for each airport for each weather condition. The airport capacity constraints model can be used to evaluate how much the theoretical capacity on airfield is reduced by crossing runways, converging runways, closely-spaced parallel runways, or airspace constraints caused by airports sharing airspace. For the Model calibration using the airport configurations at each of the 35 OEP airports, 16 constraints were identified, consisting of 9 runway interaction constraints and 7 airfield and airspace constraints. The sixteen constraint parameters were calibrated by minimizing the Root Mean Square (RMS) error between the Benchmark airport capacities and the capacities represented by the equations in the runway interaction and airfield constraints model.

Inputs and Data Availability

The Boeing Airport Capacity Constraints Model considers aircraft fleet mix, runway length, runway exit location, final approach speed, touchdown dispersion, runway braking performance, and required longitudinal and lateral separation minima. The fleet mix for each airport consists of the percentage of four aircraft types: Heavy, Boeing 757, Large, and Small.

Outputs

Equations consisting of the sum of the individual runway flows (arrivals, departures, or mixed operations) modified by the constraints that apply to each runway are defined for each airport for each weather condition.

Model Limitations

The Boeing Model does not explicitly consider assumed differences in runway occupancy times.

Table 2.2-7
SUMMARY OF THE BOEING CONSTRAINTS MODELING APPROACHES

Capacity Factor/Issue	Boeing	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Runway exit locations were considered in the single runway constraints model.
2. Runaway entrances design/ multiple entrance taxiways		Not explicitly considered.
3. Departure staging and sequencing		Not explicitly considered.
4. Runway crossings		Explicitly considered as one of the capacity-reducing constraints.
5. Parallel taxiway		Not explicitly considered except through runway exit locations.
Airline Factors		
6. Fleet mix		User specified fraction of operating aircraft that are of each type.
7. Daily distribution of aircraft activity		Not considered except through aircraft fleet mix.
Aircraft Performance		
8. Aircraft avionics equipage		Explicitly considered through its effects on the identify constraints.
9. Pavement conditions/braking action		Can be explicitly considered in the single runway constraints model.
10. Random variability		Implicitly considered in the model calibration process.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Represented through arrival-arival separations in the single runway constraints model.
12. Wake turbulence		Represented through wake turbulence operations and constraint parameters representing runway dependencies.
13. Weather		Three different weather categories are considered and represented through aircraft separation minima and the capacity reducing constraints.
14. Multiple approach technology		Can be explicitly or represented through the capacity reducing constraints.
15. Runway-specific fleet mix assignment		Explicitly considered in the single runway constraints model.

Table 2.2-7 *(page 2 of 2)*
SUMMARY OF THE BOEING CONSTRAINTS MODELING APPROACHES

Capacity Factor/Issue	Boeing	Comments/Questions
Human Factors		
16. Controller workload		Not explicitly considered.
17. Voice communications		Not explicitly considered
18. Random variability		Not explicitly considered.
Airspace Factors		
19. Departure fix restrictions		Can be explicitly considered through the appropriate capacity reducing constraints.
20. Neighboring airports		Can be explicitly considered through the appropriate capacity reducing constraints.
21. Missed approaches		Explicitly considered in the single runway constraints model.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
ANALYTICAL MODELS

8. FTA MODELS – RUNCAP AND DELAYS

Model Summary

Runway Capacity Model (RUNCAP). RUNCAP estimates the maximum number of hourly landings and takeoffs that can be conducted for a given runway system. It is an analytical model and is useful for quickly exploring the potential effects on capacity of technical improvements and/or administrative decisions. Unlike many analytical models, it is capable of handling complex runway configurations, but its simplicity and limited data requirements make it possible to generate answers more quickly than with a simulation tool such as FTA's FLAPS model.

Delays Model (DELAYS). Estimates of airport delays can be obtained through DELAYS, a computer model developed at the MIT Flight Transportation Laboratory and Flight Transportation Associates, Inc. This model is based on the earlier theoretical work which was published by Koopman. DELAYS is an analytical queuing theory model originally developed at MIT. The model treats the airport as a queuing system and uses capacity and demand streams to estimate average, hourly, and peak delays. This analytical model serves as the underlying delay calculator for FTA's DELAYSIM model.

Level of Modeling Sophistication and Model Applications

The RUNCAP Model is similar in scope to the ACM.

The DELAYS Model computes, in effect, the numerical solutions for the M/M/k and the M/D/k models plus various other useful queuing statistics. The program has been used to obtain delay estimates for various demand profiles at major airports in the United States and Europe..

Model Specifications

The latest version of the DELAYS model is programmed in the C language for personal computers using the Windows operating system.

Inputs and Data availability

The inputs to the DELAYS programs are hourly demand levels, hourly service rates, and the number of independent servers at the airport of interest, which is normally one server because the runways at an airport are operated as a coordinated unit.

Outputs

The output of the RUNCAP model is an estimate of the throughput capacity of the airfield. The output of the DELAY model is estimates of average aircraft delays.

Model Limitations

The RUNCAP and DELAYS models consider only the runways not the taxiways.

Table 2.2-8
SUMMARY OF RUNCAP MODELING APPROACHES

Capacity Factor/Issue	RUNCAP	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Can input either exit locations or average AROTS.
2. Runaway entrances design/ multiple entrance taxiways		DROTS are an input
3. Departure staging and sequencing		Only indirectly through constrained departure-departure separation
4. Runway crossings		Only indirectly through reducing number of minutes in the hour available for runway operations
5. Parallel taxiway		Only indirectly through AROTS and DROTS
Airline Factors		
6. Fleet mix		Up to four aircraft weight-speed classes can be considered
7. Daily distribution of aircraft activity		Not considered except through aircraft fleet mix
Aircraft Performance		
8. Aircraft avionics equipage		Only indirectly through buffer and separations
9. Pavement conditions/braking action		Not considered except possibly through AROTS
10. Random variability		User can specify standard deviation of various aircraft operating times
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Represented through arrival-arival separations and lengths of common approach path
12. Wake turbulence		Represented through wake turbulence operations
13. Weather		Represented through aircraft operations
14. Multiple approach technology		Certain multiple configurations specifically modeled; others must be built up manually
15. Runway-specific fleet mix assignment		Theoretically possible but overall aircraft mix must be enforced manually

Table 2.2-8 *(page 2 of 2)*
SUMMARY OF THE RUNCAP MODELING APPROACHES

Capacity Factor/Issue	RUNCAP	Comments/Questions
Human Factors		
16. Controller workload	🟥	Not considered except through constrained aircraft separations
17. Voice communications	🟥	Not considered except through constrained aircraft separations
18. Random variability	🟩	Buffer calculated as function of user-specified standard deviation and probability of violation
Airspace Factors		
19. Departure fix restrictions	🟨	Indirectly through constrained departure departure separations
20. Neighboring airports	🟥	Not considered except through constrained aircraft separations
21. Missed approaches	🟨	Considered through hardwired test of need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation if landing aircraft not clear of clouds 2 nautical miles out from threshold.

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

AIRFIELD CAPACITY MODELS
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9. FAA REDIM MODEL

Model Summary

The FAA Runway Exit Design Interactive Model (REDIM) simulates the runway roll from threshold to runway exit for a wide variety of aircraft. User specifies the runway exit locations, aircraft fleet mix, braking action, and wind conditions. Alternatively, the model can recommend runway exit locations based upon user inputs for the number of exits.

Level of Modeling Sophistication and Model Applications

REDIM provides a high level of detail for a small portion of the airport surface. It provides information on an important factor for determining runway capacity (runway occupancy times), but does not provide any runway capacity estimates. Model is useful for evaluating a large number of alternative runway exit locations and geometries in a short period of time. Runway roll methodology includes braking action, wheel slip, wind direction relative runway orientation, approach speed, aircraft weight, and touchdown distance from threshold. Model will use high speed runway roll to optimize time on runway in relation to location of runway exit versus minimum aircraft stopping distance.

Model Specifications

REDIM was developed for the FAA by Virginia Tech University. Model source code is Microsoft Quick BASIC with assembly language routines for screen I/O. Code is EGA/VGA monitor specific.

Inputs and Data availability

REDIM accepts all user inputs from the keyboard. It has several master files that contain aircraft performance information.

Outputs

Model writes all output to the screen. The user must write down outputs on screen and re-enter them into other programs.

Model Limitations

Model does not consider runway crossing or other taxiway operations.

Table 2.2-9
SUMMARY OF REDIM MODELING APPROACHES

Capacity Factor/Issue	REDIM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Model computes runway occupancy time based upon a random draw for touchdown distance down runway, and aircraft de-acceleration and wheel slip model. Model accepts different acceleration rates based on braking action switch (good, fair, poor). Minimum stopping distance compared to available runway exits. Model accepts a coast velocity input for high-speed runway roll prior to completing rest of aircraft braking.
2. Runaway entrances design/ multiple entrance taxiways		Not considered
3. Departure staging and sequencing		Not considered
4. Runway crossings		Not considered
5. Parallel taxiway		Assumes runway has a parallel taxiway avaliable at user-specified spacing from runway
Airline Factors		
6. Fleet mix		Fleet mix table
7. Daily distribution of aircraft activity		Not considered
Aircraft Performance		
8. Aircraft avionics equipage		Not considered
9. Pavement conditions/braking action		Yes (see runway exits above)
10. Random variability		Random variables for aircraft speeds and touchdown distances
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Not considered
12. Wake turbulence		Not considered
13. Weather		Wet versus dry runway, braking action
14. Multiple approach technology		Not considered
15. Runway-specific fleet mix assignment		Single runway model. Fleet mix customized for each runway.

Table 2.2-9 *(page 2 of 2)*
SUMMARY OF REDIM MODELING APPROACHES

Capacity Factor/Issue	REDIM	Comments/Questions
Human Factors		
16. Controller workload		Not considered
17. Voice communications		Not considered
18. Random variability		Random variables for aircraft speeds and touchdown distances
Airspace Factors		
19. Departure fix restrictions		Not considered
20. Neighboring airports		Not considered
21. Missed approaches		Not considered

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SIMULATION MODELS

10. FTA MODELS—FLAPS AND DELAYSIM

Model Summary

Flexible Airport Simulation (FLAPS). FLAPS is a stochastic, event-driven simulation models aircraft from the approach fix to the runway exit and from the runway departure queue to the departure fix. It is easily adaptable to any geometry. FLAPS produces detailed statistical outputs on runway capacity and utilization, aircraft delays, exit use, and runway queues. Due to its computational efficiency and simple input structure, FLAPS is characterized by a very low cost per computer run compared to other similar airport simulation packages. The stochastic nature of the FLAPS model produces not only an assessment of capacity, delay, runway use, and exit utilization, but also a statistical output that indicates the potential variation in these results.

The simulation of the landing process is based on a physical model of aircraft performance characteristics. All phases of approach, flare, touchdown, and braking are considered, creating an accurate representation of an aircraft's potential to utilize an exit. It is therefore possible to explore the effects on runway capacity and delays of new runway exits, high-speed exits, wet runway conditions, or runway surfaces designed for improved braking.

Delay Simulation (DELAYSIM). DELAYSIM was originally developed for Massport at Boston Logan International Airport. The model simulates how air traffic controllers might use the airport's runways based on specified demand characteristics and actual weather observations. It also predicts hour-by- hour runway utilization, and estimates the associated aircraft delays.

DELAYSIM operates by sequencing through hourly weather observations and simulating the controllers' selection of runway for each hour and averages the results to produce annual operating statistics. The model also has the capability of selecting the available configuration with the maximum capacity in each hour, which normally would represent the controllers' unconstrained preference.

Level of Modeling Sophistication and Model Applications

DELAYSIM has most recently been used in studies at the San Francisco Bay Area airports (SFO, OAK, and SJC), Boston Logan International Airport, Schiphol Airport, and Sydney Airport.

Model Specifications

The FLAPS Model is written in the C++ computer language and operates on any IBM-compatible PC.

Inputs and Data availability

FLAPS requires the user to specify inputs on the three primary factors which affect runway capacity: (1) aircraft characteristics and fleet mix, (2) runway layout and availability, and (3) air traffic control operating procedures.

Outputs

The primary output of each FLAPS model run is the capacity of a runway configuration (the maximum number of aircraft arrivals and departures that can be achieved in one hour under given fleet mix, weather, and air traffic control conditions). FLAPS also produces detailed statistics on delays, runway use, and exit utilization by aircraft class.

DELAYSIM produces detailed delay statistics and generates configuration and runway use statistics by month, time-of-day, and day-of-week.

Model Limitations

The FLAPS Model is a runway-centric model in that it does not explicitly include the impact of taxiway congestion, gate availability, runway crossings, and departure queue management on capacity.

Table 2.2-10
SUMMARY OF FLAPS MODELING APPROACHES

Capacity Factor/Issue	FLAPS	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)	🟩	Explicitly models the aircraft landing process and exit selection.
2. Runaway entrances design/ multiple entrance taxiways	🟩	DROTS are an input to the model
3. Departure staging and sequencing	🟨	Only indirectly through constrained departure-departure separation
4. Runway crossings	🟨	Considered only indirectly
5. Parallel taxiway	🟨	Considered only indirectly through runway exits and entrances
Airline Factors		
6. Fleet mix	🟩	Up to 16 aircraft weight-speed classes can be considered
7. Daily distribution of aircraft activity	🟥	Not considered except through the flight schedule inputs and aircraft fleet mix
Aircraft Performance		
8. Aircraft avionics equipage	🟨	Only indirectly through aircraft separations and runway dependencies
9. Pavement conditions/braking action	🟥	Considered in the explicitly modeled aircraft landing process
10. Random variability	🟩	User can specify standard deviation of various aircraft operating times
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	Represented through arrival-arival separations and lengths of common approach path
12. Wake turbulence	🟩	Represented through wake turbulence separations
13. Weather	🟩	Represented through aircraft separations
14. Multiple approach technology	🟨	Can model any runway configuration with up to__? runway ends
15. Runway-specific fleet mix assignment	🟥	Can be explicitly modeled

Table 2.2-10 *(page 2 of 2)*
SUMMARY OF FLAPS MODELING APPROACHES

Capacity Factor/Issue	FLAPS	Comments/Questions
Human Factors		
16. Controller workload		Not considered except through constrained aircraft separations
17. Voice communications		Not considered except through constrained aircraft separations
18. Random variability		Explicitly considers in the Monte Carlo stochastic, discrete-event simulation
Airspace Factors		
19. Departure fix restrictions		Indirectly through constrained departure departure separations
20. Neighboring airports		Not considered except through constrained aircraft separations
21. Missed approaches		Considered through need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation in marginal and poor weather conditions.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
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11. LANDRUM & BROWN GATESIM MODEL

Model Summary

GATESIM is an airport surface aircraft movement model that evaluates aircraft movements from arrival runway threshold to departure runway far end. Primary model outputs are delays and throughput (by runway, by taxiway, by terminal area, by aircraft, by hour, etc.) Animation is prepared through post-process.

GATESIM requires a pre-processor (AIRSIM) to provide arrival runway threshold, exit points and times. The model moves arriving aircraft from runway exit to gate, and departing aircraft from gate to departure runway entrance. Long ground time aircraft can be towed off of gates to remote stands and brought back later to a different gate for departure.

Level of Modeling Sophistication and Model Applications

GATESIM is a graphical airport surface aircraft movement simulation model. Aircraft movement is from point to point, each point being approximately 250 to 300 feet from the previous point. Only one aircraft at a time can occupy a point on the airfield. Aircraft taxi speeds (random variability) are defined for movement and non-movement areas. Taxi speeds can also vary by aircraft type.

Points within a taxi-lane can be paired to limit aircraft type passing where smaller aircraft can pass each other while larger aircraft are restricted to one direction movements.

GATESIM models runway crossing movements and the interaction of departure runways and arrival runways. GATESIM has the same departure runway model that AIRSIM has, but operates it in a single airport mode.

Model Specifications

GATESIM was developed by Landrum & Brown in 1970 and was subsequently updated many times until the mid-1990s. The model is written in FORTRAN. The model has a preprocessor that allocates demand to gates and runways based upon a user target balance of demand and gate allocation rules. The model outputs binary and text files that are readable by several post-processing programs. Users change inputs by editing input text files. The model has a graphical input program for establishing the airfield movement network.

Inputs and Data Availability

GATESIM has six input files:

- Aircraft flight schedules – Convert from OAG format, add non-scheduled flights from various sources
- Airport geometry file – text file describing taxiway centerlines and types, runway intersection distances, intersection departure points, runway lengths, etc.
- Gate geometry file – text file describing the size of gate and which airlines are allowed to use each gate. Gate sizes can be limited by aircraft sizes in adjacent gates. Gates are associated to a taxiway segment adjacent to the gate.
- Aircraft performance database – various airspace, runway exit, and taxi speeds, runway touchdown points, aircraft wake-turbulence classifications, etc.
- Airport and airspace usage file – defines allocation of fixes to runways, runway configuration change thresholds (when to add runways to the base configuration in response to demand), runway usage (arrival, departure, mixed), capture distance to hold departure on intersecting or close parallel runway, separation distances (arrivals) and times (departures).
- Taxi route file – defines the taxi path between runway exit and apron area entrance, and between apron area exit and runway entrances. Separate taxi routes are defined to aircraft holding pads, and hangars for long ground time aircraft.

Outputs

The model provides a detailed record of the history of actions that occurred for each aircraft. Post-processing programs categorize information from this detail record to provide information on delays and runway throughputs. Model provides an aircraft movement detail file used by an animation play-back program.

Model Limitations

Model requires AIRSIM to determine arrival runway exit locations and times. Model does not consider air traffic controller workload or voice communications.

Table 2.2-11
SUMMARY OF GATESIM MODELING APPROACHES

Capacity Factor/Issue	GATESIM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Runway exit information provided by AIRSIM model (exit location and time at exit for each aircraft)
2. Runaway entrances design/ multiple entrance taxiways		Multiple runway entrances and intersection departures accommodated.
3. Departure staging and sequencing		Model supports up to eight fixes per runway. Different separations used if successive departures are to different fixes. Model does not optimize departure sequence.
4. Runway crossings		Yes
5. Parallel taxiway		Model does not support back taxi on runway. Runway roll will be extended if runway exit is occupied.
Airline Factors		
6. Fleet mix		Works from an airline flight schedule
7. Daily distribution of aircraft activity		Works from an airline flight schedule. Early/Late arrival distributions also considered. Airline gate rescheduling for landing aircraft without gates. Penalty box for aircraft without gates upon arrival. Model runway supports partial configuration change (ground reroutes, etc.) for departure runways only. Approach change handled by AIRSIM.
Aircraft Performance		
8. Aircraft avionics equipage		Not included
9. Pavement conditions/braking action		No (see runway exits above)
10. Random variability		Many random variables for aircraft taxi speeds and separations, early/late arrival, aircraft push-back times (variable also by aircraft type, tow-in distribution. Airline operations (not aircraft operations related) delay distribution.

Table 2.2-11 *(page 2 of 2)*
SUMMARY OF GATESIM MODELING APPROACHES

Capacity Factor/Issue	GATESIM	Comments/Questions
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	VFR and IFR
12. Wake turbulence	🟩	Departure separation times for four aircraft type classes (small, large, B-757 and heavy). Note: GATESIM requires AIRSIM run for arrival runway threshold and exit information – models must be run in tandem.
13. Weather	🟩	Two classes VMC and IMC
14. Multiple approach technology	🟨	Approach runways decided by AIRSIM. Model handles up to ten runways.
15. Runway-specific fleet mix assignment	🟨	Aircraft types restricted from runway by weight class.
Human Factors		
16. Controller workload	🟥	Not considered
17. Voice communications	🟥	Not considered
18. Random variability	🟨	Random variables for separations, taxi speeds, push-back times, and on-time gate departure (arrival time variability determined in AIRSIM).
Airspace Factors		
19. Departure fix restrictions	🟥	Not considered
20. Neighboring airports	🟥	Not considered
21. Missed approaches	🟥	Not considered

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SIMULATION MODELS

12. LANDRUM & BROWN AIRSIM MODEL

Model Summary

AIRSIM is a terminal area (TRACON) airspace and airport runway delay model that models up to three airports with up to ten runways per airport. Primary model outputs are delays and throughput (by runway by aircraft, by hour, etc.) Animation is prepared through post-process.

Model starts arriving aircraft at initial entry into the terminal area airspace and sequences aircraft arrival traffic from multiple fixes to a single runway. Model computes vectoring time required through speed control and path stretching. Path stretching limited by maximum length of vectoring time that can be accommodated (user specified). Speed control limits based upon aircraft performance database.

Model starts departing aircraft at initial entry to the departure queue and sequences departing aircraft from multiple runways through departure fixes. Model computes vectoring time through speed control and path stretching. Path stretching limited by maximum length of vectoring time that can be accommodate (user specified).

Level of Modeling Sophistication and Model Applications

AIRSIM is a non-graphical airport runway and airspace simulation model. Arrival airspace is represented by a series of links between initial entry points to the terminal area airspace to a single common approach link to the runway threshold. Aircraft speeds (random variability) are defined for the initial links and for the common approach link. An airspace entry point can have links to more than one common approach link. A common approach link can feed a pair of runways using diagonal separations.

AIRSIM tracks the number of arrivals on approach to each runway and prevents entry to the airspace when a threshold number of aircraft is exceeded or a maximum vectoring time would be exceeded. The model simulates a holding stack at the edge of airspace and adds a one minute wait to the airspace entry time and will retry airspace entry later.

Departure airspace links connect from the far end of each departure runway to a fix at the edge of the terminal area airspace. A speed change can occur at a user defined midpoint of the link. One runway can serve multiple links. When aircraft go to different links, different time separations are applied.

Model Specifications

AIRSIM was developed by Landrum & Brown in 1972 and was subsequently updated many times until the mid-1990s. The model is written in FORTRAN. The model has a preprocessor that allocates demand to fixes and runways based upon a user target balance of demand. The model outputs binary and text files that are readable by several post-processing programs. Users change inputs by editing input files.

Inputs and Data availability

AIRSIM has five input files:

- Aircraft flight schedules – Convert from OAG format, add non-scheduled flights from various sources
- Airport geometry file – text file describing runway exit distances and type, intersection distances, and expected taxi times between runway exits/entrances and aircraft parking aprons), intersection departure points, runway lengths, etc.
- Airspace geometry file – text file describing links between airspace entrance points and common approach path links and links between departure runways and airspace exit points, outer marker locations (speed change on approach
- Aircraft performance database – various airspace, runway exit, and taxi speeds, runway touchdown points, aircraft wake-turbulence classifications, etc.
- Airport and airspace usage file – defines allocation of fixes to runways, runway configuration change thresholds (when to add runways to the base configuration in response to demand), runway usage (arrival, departure, mixed), capture distance to hold departure on intersecting or close parallel runway, separation distances (arrivals) and times (departures).

Outputs

The model provides a detailed record of the history of actions that occurred for each aircraft. Post-processing programs categorize information from this detail record to provide information on delays and runway throughputs.

Model Limitations

Model does not consider runway crossing or other taxiway operations.

Table 2.2-12
SUMMARY OF AIRSIM MODELING APPROACHES

Capacity Factor/Issue	AIRSIM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Model computes runway occupancy time based upon a random draw for touchdown distance down runway, and aircraft de-acceleration model. Model accepts different acceleration rates based on braking action switch (good, fair, poor). Minimum stopping distance compared to available runway exits. Model accepts a coast velocity input for high-speed runway roll prior to completing rest of aircraft braking.
2. Runaway entrances design/ multiple entrance taxiways		Multiple runway entrances and intersection departures accommodated.
3. Departure staging and sequencing		Model handles up to 8 departure fixes per runway. Uses different separation (input) values if fix is different for successive departures. Model examines demand by runway and reallocates fix to runway assignments to achieve input runway balance. Model does not optimize departure queue ordering.
4. Runway crossings		Not considered
5. Parallel taxiway		Model assumes that taxiway is available that leads from runway exit to gate. Distance from runway exit to gate is input. Distance from gate to runway entrance is input. Taxi speed is hardwired at 15 knots.
Airline Factors		
6. Fleet mix		Works from an airline flight schedule
7. Daily distribution of aircraft activity		Works from an airline flight schedule. Early/Late arrival distributions also considered.
Aircraft Performance		
8. Aircraft avionics equipage		Not considered
9. Pavement conditions/ braking action		Yes (see runway exits above)
10. Random variability		Many random variables for aircraft speeds and separations, early/late arrival, and aircraft push-back times

Table 2.2-12 *(page 2 of 2)*
SUMMARY OF AIRSIM MODELING APPROACHES

Capacity Factor/Issue	AIRSIM	Comments/Questions
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	VFR and IFR
12. Wake turbulence	🟩	Approach separation distances and departure separation times for four aircraft type classes (small, large, B-757 and heavy)
13. Weather	🟩	Three classes VMC, MVMC and IMC. Partial days of each.
14. Multiple approach technology	🟩	Diagonal separations for dependent parallel approaches. Triple and Quad approaches, with up to 10 active runways per airport.
15. Runway-specific fleet mix assignment	🟨	Aircraft can be restricted from runways by weight class
Human Factors		
16. Controller workload	🟨	Model has an approach sector maximum workload variable.
17. Voice communications	🟨	Not considered
18. Random variability	🟨	Random variable included for compression on final approach
Airspace Factors		
19. Departure fix restrictions	🟨	Miles in trail only
20. Neighboring airports	🟨	Sequence departures from multiple airports. Up to 3 airports within local airspace.
21. Missed approaches	🟨	Considered through hardwired test of need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation if landing aircraft not clear of clouds 2 nautical miles out from threshold. (Missed approaches are an indication that sequencing algorithm failed – never happens).

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
SIMULATION MODELS

13. THE RUNWAY DELAY SIMULATION MODEL (RDSIM)

Model Summary

The Runway Delay Simulation Model (RDSIM) is a sub-component of ADSIM that focuses only on an airport's final approach, runway, and runway exit. RDSIM traces the path of each aircraft through space and time on the runway network. The runways and exit taxiways are represented by a series of links and nodes.

Level of Modeling Sophistication and Model Applications

RDSIM is generally used for simplified analyses were only the runway operations are considered.

Model Specifications

Like ADSIM, RDSIM was written originally in FORTRAN and is a discrete event simulation model and employs Monte Carlo sampling techniques. The following model parameters are treated as random variables:

- Aircraft separations
- Aircraft approach speed
- Runway occupancy times
- Runway exit-taxiway (exit) choice
- Arrival lateness distribution
- Runway inter-arrival gap
- Intersection takeoff

Inputs and Data availability

RDSIM utilizes the following user-specified input data:

- Runway Physical Characteristics
- Procedures
- Aircraft Operational Characteristics
- Runway Geometry
- Aircraft Schedule

Outputs

The model generates the following output data for analyses of the airfield performance:

- Arrival and departure delays by hour (or quarter-hour), by aircraft class, by runway, by airfield components, and by airfield operations
- Composite hourly (or quarter-hourly) flow rates, travel times, and delays for arrivals and departures

Model Limitations

RDSIM considers implicitly only the final approach (final approach path leading to each runway) and initial departure airspace (initial departure path leading from each runway).

Table 2.2-13

SUMMARY OF RDSIM MODELING APPROACHES

Capacity Factor/Issue	RDSIM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Model computes runway occupancy time based upon a random draw using an empirical distribution of exit use by aircraft type for each runway.
2. Runaway entrances design/ multiple entrance taxiways		Multiple runway entrances and intersection departures accommodated.
3. Departure staging and sequencing		Model handles up to 8 departure fixes per runway and can accept different separation (input) values if fix is different for successive departures.
4. Runway crossings		Not considered except when a simplified ADSIM network is used where only the runways, exit taxiways, and taxiways crossing runways are specified in the link node diagram.
5. Parallel taxiway		Only exit taxiways are considered.
Airline Factors		
6. Fleet mix		Works from an airline flight schedule
7. Daily distribution of aircraft activity		Works from an airline flight schedule. Stochastic early/Late arrival distributions also considered.
Aircraft Performance		
8. Aircraft avionics equipage		Not considered
9. Pavement conditions/ braking action		Indirectly considered through the runway exit use distributions
10. Random variability		Many random variables for aircraft speeds and separations, early/late arrival, etc., as described in the foregoing summary.

Table 2.2-13 *(page 2 of 2)*
SUMMARY OF RDSIM MODELING APPROACHES

Capacity Factor/Issue	RDSIM	Comments/Questions
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	VFR and IFR
12. Wake turbulence	🟩	Approach separation distances and departure separation times for four aircraft type classes (small, large, B-757 and heavy)
13. Weather	🟩	Three classes VMC, MVMC, and IMC. Partial days of each.
14. Multiple approach technology	🟩	Independent, dependent, and intersecting runway configurations can be modeled through specifying runway dependencies.
15. Runway-specific fleet mix assignment	🟨	Different aircraft fleet mixes can be specified through the airline schedule by the runway assignments.
Human Factors		
16. Controller workload	🟨	Not explicitly modeled. Can be implicitly modeled through larger than normal in trail separations.
17. Voice communications	🟨	Not considered
18. Random variability	🟨	Buffers can be added to the minimum aircraft separation requirements to represent the accuracy with which controllers can deliver aircraft to the final approach fix
Airspace Factors		
19. Departure fix restrictions	🟨	Larger than standard in trail separations for departures can be specified.
20. Neighboring airports	🟨	Not explicitly considered. Can be implicitly considered through larger than normal aircraft separations.
21. Missed approaches	🟨	Considered through hardwired test of need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation if landing aircraft not clear of clouds 2 nautical miles out from threshold.

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

**AIRFIELD CAPACITY MODELS
REVIEW OF AVAILABLE MODEL
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14. THE AIRFIELD DELAY SIMULATION MODEL (ADSIM)

Model Summary

The Airfield Delay Simulation Model (ADSIM), which was developed by Peat, Marwick, Mitchell & Co. (now LeighFisher), is a discrete event simulation model that calculates travel times, delays, and flow rates to analyze components of an airfield. The FAA validated the model at Chicago O'Hare Airport in 1977.

ADSIM traces the path of each aircraft through space and time on the airfield network. The airfield is represented by a series of links and nodes depicting the paths. The model traces each aircraft by continually advancing clock time and recording its new location. It then processes the records of aircraft movement and produces desired outputs such as delays, queue lengths, travel times, and flow rates.

Level of Modeling Sophistication and Model Applications

ADSIM is applicable to all types of airfield configurations. Consequently, the model does not contain any airport specific or aircraft-class specific data; all data are input. Although ADSIM can simulate a non-tower General Aviation airfield or Chicago O'Hare International Airport, model application is relatively expensive because of the model's complexity and the volume of input data required. Therefore, the model is most often applied at large airports.

By manipulating the input data, unusual events can be simulated. For example, the impact of a change in weather conditions or the effect of a storm passing through the area may be simulated by changing aircraft separations, runway usage, and aircraft operating characteristics in the middle of the model run.

Model Specifications

ADSIM was written originally in FORTRAN and was divided into two programs. The first program (the Simulation Module) reads the input data, performs the simulation, and writes the detailed results to several intermediate output files. Those files are sorted and read by the second program (the Averaging Module), which produces the ADSIM output reports. The FAA, through CSSI, has recently reprogrammed the model in C++. The reprogrammed version is known as ADSIM+.

ADSIM is a discrete event simulation model and employs Monte Carlo sampling techniques. Variable time increments are used as the time flow mechanism. Therefore, clock time advances by the amount necessary to cause the next most imminent event to take place. To achieve a statistically significant result, a day of operations is simulated several times and the average results are presented along with their standard deviations. The number of model replications is controlled by the user and should reflect the variability in the input data. Each replication starts with a user- specified random number seed so it is possible to duplicate any particular cycle if desired.

Using Monte Carlo sampling techniques, the model simulates the day-to- day variations encountered in real life. The following model parameters are treated as random variables:

- Aircraft separations
- Aircraft approach speed
- Runway occupancy times
- Runway exit-taxiway (exit) choice
- Gate service time
- Arrival lateness distribution
- Runway crossing delay limits
- Runway inter-arrival gap
- Intersection takeoff
- Link transit time

Inputs and Data availability

ADSIM utilizes the following user-specified input data:

- Airfield Physical Characteristics
- Procedures
- Aircraft Operational Characteristics
- Airfield Geometry
- Airline Gates
- Route Data
- Two-Way Path Data
- Aircraft Schedule

Outputs

The model generates the following output data for analyses of the airfield performance:

- Arrival and departure delays by hour (or quarter-hour), by aircraft class, by runway, by airfield components, and by airfield operations
- Delays for runway crossing and taxiway queue links
- Travel times for various segments of departure and arrival operations
- Composite hourly (or quarter-hourly) flow rates, travel times, and delays for arrivals and departures

Model Limitations

ADSIM considers implicitly only the final approach (final approach path leading to each runway) and initial departure airspace (initial departure path leading from each runway).

Table 2.2-14

SUMMARY OF ADSIM MODELING APPROACHES

Capacity Factor/Issue	ADSIM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Model computes runway occupancy time based upon a random draw using an empirical distribution of exit use by aircraft type for each runway.
2. Runaway entrances design/ multiple entrance taxiways		Multiple runway entrances and intersection departures accommodated.
3. Departure staging and sequencing		Model handles up to 8 departure fixes per runway and can accept different separation (input) values if fix is different for successive departures.
4. Runway crossings		Runway crossings are explicitly modeled and tied to runway arrival and departure operations. User specifies a runway crossing clearance time for each crossing and the clearest time for each operation to pass the crossing point.
5. Parallel taxiway		All taxiways are represented by a link node diagram.
Airline Factors		
6. Fleet mix		Works from an airline flight schedule
7. Daily distribution of aircraft activity		Works from an airline flight schedule. Stochastic early/Late arrival distributions also considered.
Aircraft Performance		
8. Aircraft avionics equipage		Could be reflected indirectly through the assumed buffer.
9. Pavement conditions/ braking action		Indirectly considered through the runway exit use distributions
10. Random variability		Many random variables for aircraft speeds and separations, early/late arrival, etc., as described in the foregoing summary.

Table 2.2-14 *(page 2 of 2)*
SUMMARY OF ADSIM MODELING APPROACHES

Capacity Factor/Issue	ADSIM	Comments/Questions
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	VFR and IFR
12. Wake turbulence	🟩	Approach separation distances and departure separation times for four aircraft type classes (small, large, B-757 and heavy)
13. Weather	🟩	Three classes VMC, MVMC, and IMC. Partial days of each.
14. Multiple approach technology	🟩	Independent, dependent, and intersecting runway configurations can be modeled through specifying runway dependencies.
15. Runway-specific fleet mix assignment	🟨	Different aircraft fleet mixes can be specified through the airline schedule by the runway assignments.
Human Factors		
16. Controller workload	🟨	Not explicitly modeled. Can be implicitly modeled through larger than normal in trail separations.
17. Voice communications	🟨	Not considered
18. Random variability	🟨	Buffers can be added to the minimum aircraft separation requirements to represent the accuracy with which controllers can deliver aircraft to the final approach fix
Airspace Factors		
19. Departure fix restrictions	🟨	Larger than standard in trail separations for departures can be specified.
20. Neighboring airports	🟨	Not explicitly considered. Can be implicitly considered through larger than normal aircraft separations.
21. Missed approaches	🟨	Considered through hardwired test of need to protect for missed approach by providing a 2-nautical-mile departure-arrival separation if landing aircraft not clear of clouds 2 nautical miles out from threshold.

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

AIRFIELD CAPACITY MODELS
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15. THE MITRE RUNWAYSIMULATOR MODEL

Model Summary

To overcome some of the limitations of the Airfield Capacity Model for handling very complex runway systems, MITRE recently developed an analysis tool called the Airport Capacity Analysis Through Simulation (ACATS) model, which was recently renamed the “runwaySimulator.” The major differences between runwaySimulator and models like the Runway Delay Simulation Model (RDSIM) (i.e., simulation models of runways only) are (1) runwaySimulator does not require a detailed airline schedule, instead it generates continuous traffic streams of a specified aircraft mix to each of the runways so there is always an aircraft waiting to land and waiting to take off, (2) one can simulate shorter time periods (just long enough to load up to system to a steady state), and (3) the major outputs of the runwaySimulator are maximum runway throughput rates, not aircraft delays.

The runwaySimulator defines runway capacity as the maximum average sustainable throughput in aircraft per hour. The capacity as defined is a function of aircraft fleet mix (including ratio of arrivals to departures), ATC separation procedures, and runway configuration.

Level of Modeling Sophistication and Model Applications

The runwaySimulator has advantages over simple analytical capacity models and queuing models. Simple queuing models fail because the service times are dependent on the sequence of arrivals. Steady-state analytical models fail to capture the dynamics in very complex runway systems. The runwaySimulator model captures the dynamics of complex airports, and avoids the costly set-up process by creating a simulation.

The runwaySimulator enables the user explicitly model complex runway-use configurations, including having different aircraft mixes on different runways, runway dependencies, and airspace dependencies. The runwaySimulator also can be used to estimate aircraft delay if the user specifies a traditional input flight schedule rather than the constant demand for service typically used for estimating throughput capacity.

Model Specifications

The runwaySimulator uses a general purpose simulation engine. The central idea in the algorithm is that when one aircraft uses an element of the network, it blocks another aircraft from using some other element, until an amount of time has elapsed. The pairwise nature of the blocking rules enables an efficient simulation and is easily modified for case studies.

Inputs and Data Availability

The runwaySimulator Engine is completely controlled by the data and parameters passed from the User Interface. It simulates the airport's operations, maintains required separation, distributes aircraft across runways "intelligently, and ensures a constant supply of desired aircraft mix.

The graphical user interface (GUI) allows the user to specify the ATC rules and runway geometry of the airport. The demand pattern is presented by the aircraft fleet mix file in the Arrival-Departure ratio file. The wake vortex separation rules require time or distance parameters for the different weight classes.

Outputs

Outputs of the model include a history file that is post-processed to generate desired statistics and graphs, and an animation file that can be used to produce a visualization.

There are two primary results of a runwaySimulator analysis: (1) a set of capacities plotted on an arrival versus Departure graft and connected by lines to form a Pareto frontier or capacity curve for used as input to other models, and (2) a log of simulation operations that can be used to analyze particular operational conditions and bottlenecks, which can be animated to provide an easily understood visual of how the airport has been modeled.

Model Limitations

The runwaySimulator software runs on a PC running Microsoft Windows and requires a license for the SLX simulation software used by the simulation engine.

Table 2.2-15
SUMMARY OF THE RUNWAYSIMULATOR MODELING APPROACHES

Capacity Factor/Issue	Runway Simulator	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)		Can input either exit locations or average AROTS. Inputs are similar to those for the ACM
2. Runaway entrances design/ multiple entrance taxiways		DROTS are an input. Period inputs are similar to those for the ACM
3. Departure staging and sequencing		Only indirectly through constrained departure-departure separation.
4. Runway crossings		Not explicitly considered.
5. Parallel taxiway		Considered only indirectly through AROTS and DROTS.
Airline Factors		
6. Fleet mix		Specified in terms of aircraft weight-speed classes.
7. Daily distribution of aircraft activity		Not considered except through aircraft fleet mix. In "delay mode" the runwaySimulator can accept an airline schedule.
Aircraft Performance		
8. Aircraft avionics equipage		Only indirectly through stochastic buffers and aircraft separations, similar to the ACM.
9. Pavement conditions/braking action		Only indirectly through aircraft mix that can use runway and AROTS.
10. Random variability		User can specify standard deviation of various aircraft operating times.
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches		Represented through arrival-arival separations and lengths of common approach path.
12. Wake turbulence		Represented through wake turbulence operations and runway dependencies.
13. Weather		Represented through aircraft separations and runway dependencies.
14. Multiple approach technology		Can be explicitly modeled in the runwaySimulator, unlike the ACM.
15. Runway-specific fleet mix assignment		Can be input into model and enforces overall “airfield mix”.

Table 2.2-15 *(page 2 of 2)*
SUMMARY OF RUNWAYSIMULATOR MODELING APPROACHES

Capacity Factor/Issue	Runway Simulator	Comments/Questions
Human Factors		
16. Controller workload		Not considered except through constrained aircraft separations.
17. Voice communications		Not considered except through constrained aircraft separations.
18. Random variability		Buffer calculated as function of user-specified standard deviation and probability of violation.
Airspace Factors		
19. Departure fix restrictions		Can be explicitly modeled in the runwaySimulator.
20. Neighboring airports		Can be explicitly modeled in the runwaySimulator.
21. Missed approaches		Can be explicitly modeled in the runwaySimulator.

Model fully addresses capacity factor

Model partially or indirectly addresses capacity factor

Model does not address capacity factor

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16. TAAM: TOTAL AIRSPACE & AIRPORT MODELER

Model Summary

TAAM (Total Airspace & Airport Modeler) is fast-time simulation designed to model the movement of individual aircraft operations through the airspace and on the ground in accordance with user-specified air traffic control and ground control rules and aircraft manufacturer-specified aircraft performance characteristics.

TAAM provides a visual modeling environment that is easily understood by key stakeholders. The model enables the user to program in flexible taxiway, runway, and gate usage rules, which permit realistic modeling of aircraft ground movements.

TAAM is a discrete event simulation that models the kinematics of the aircraft trajectories. Each trajectory is defined by a flight plan, such as a SID, STAR, or taxiway routing. The simulation generates trajectory tracks for each of these flight plans. Progress on the flight plan is determined by performance characteristics of each phase of flight and the by rules of operation for each segment. Stochastic behavior is inserted in the simulation in the form of distributions for speed.

Level of Modeling Sophistication and Model Applications

TAAM is the highest level of modeling sophistication since it is applied for detailed planning of complex airfields. TAAM is a highly complex simulation and delay model, at a level of sophistication which is out of the scope of this research.

TAAM has been used at many airports throughout the world, by airport operators, consultants, airlines, and airspace planners for applications such as the ones listed below.

- Airport capacity (gate, taxiway, runway capacity)
- Planning airport improvements, extensions
- De-icing operations
- Noise impact
- Impact of severe weather
- Design of terminal area procedures (SIDs/STARs)
- Design of terminal area ATC sectors
- Controller workload assessment

Model Specifications

TAAM is written in C, C++ and Java. TAAM is designed on an open systems platform with a client/server architecture. TAAM can be run in either Linux or Windows. With a typical hardware configuration, TAAM is capable of running 35,000 flights a day (with conflict detection/resolution disabled) in less than 4 hours. TAAM has four modules:

the Interactive Data Input System (IDIS); the simulation engine (SIM); the Report Presentation Facility (RPF), which reports output; and Gtool, an input mapping program.

Inputs and Data Availability

The main inputs to TAAM include (1) flight schedule, (2) airspace and airport geometric layout in CAD and properties, (3) SID/STAR geometry and characteristics, (4) aircraft performance characteristics, (5) air traffic procedures, and (6) airport usage rules. The airport usage rules are user-defined and control elements such as runway use, SID/STAR selection, taxiway usage, gate usage, and pushbacks.

Outputs

A 2D or 3D graphical visualization of the simulation is generated. The graphical output can be viewed in several windows simultaneously, each window having an independent 2D or 3D view with the scale ranging from 30 m to 40,000 km.

Outputs also include statistics and data for the following:

- System delays
- Conflicts: counts by degree of severity, whether successfully resolved or not
- Airport movements, delays, operations on taxiways and runways, runway occupancy
- Airspace operation metrics such as usage of routes, sectors, fixes and coordination
- Noise contours
- Total fuel burnt
- Costs: aggregate, fuel, non-fuel
- Controller workloads
- Individual Aircraft flight profiles
- Scenario generation e.g., for real-time ATC simulators or other playback
- "Show Logic" diagnostics which gives the operator an insight into TAAM's decision making process
- Text messages (extent and content user selectable) which contain further details of TAAM events

Model Limitations

The main limitation of using TAAM for real-world applications is its complexity, and accordingly its expense and timeframe. TAAM requires special skills and dedicated start-up period, and maintaining a skilled-staff is expensive. Start-up costs can be high, and the duration of the simulation effort can be lengthy. TAAM is not appropriate for use in smaller airport or studies where capacity is not a significant issue.

Table 2.2-16
SUMMARY OF TAAM MODELING APPROACHES

Capacity Factor/Issue	TAAM	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)	■	Exit locations specified along with aircraft speed/deceleration
2. Runaway entrances design/ multiple entrance taxiways	■	Entrances may be specified, Rules used to determine when used.
3. Departure staging and sequencing	■	Indirectly through schedule and/or rule-base.
4. Runway crossings	■	Rule-based
5. Parallel taxiway	■	Taxiway can be specified. Rule-base directs traffic.
Airline Factors		
6. Fleet mix	■	Sixty aircraft weight-speed classes can be considered
7. Daily distribution of aircraft activity	■	Directly through flight schedule
Aircraft Performance		
8. Aircraft avionics equipage	■	Indirect via aircraft performance and other infrastructure/ATC parameters.
9. Pavement conditions/braking action	■	Directly through aircraft characteristics.
10. Random variability	■	Standard deviation of various aircraft operating times and speed
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	■	Separation diatance, runway assignment rules, and approach/departure routes.
12. Wake Vortex	■	Separation diatances and runway assignment rules
13. Weather	■	Indirect through separation, aircraft performance, and assignment rules
14. Multiple approach technology	■	Parameters may be set to emulate
15. Runway-specific fleet mix assignment	■	Directly through runway use rules.

Table 2.2-16 *(page 2 of 2)*
SUMMARY OF TAAM MODELING APPROACHES

Capacity Factor/Issue	TAAM	Comments/Questions
Human Factors		
16. Controller workload	🟩	Model of ATC workload (13 component model)
17. Voice communications	🟥	Indirect
18. Random variability	🟨	Indirect through parameters
Airspace Factors		
19. Departure fix restrictions	🟨	Indirectly through constrained departure-departure separations
20. Neighboring airports	🟨	Indirctly through constrained aircraft separations, or modeling a system of multiple airports
21. Missed approaches	🟥	Not considered

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

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17. FAA SIMMOD MODEL

Model Summary

FAA's Airport and Airspace Simulation Model is an event-step simulation model which traces the movement of individual aircraft and simulated ATC actions required to ensure aircraft operates within procedural rules. It is a discrete-event simulation model that tracks the movement of individual aircraft as they travel through the airspace and on the ground.

The model can be used to simulate in detail: a full individual airfield (including runways, taxiways, and apron areas); an airfield and its associated terminal airspace; a regional system of airports and the associated airspace; or, a regional volume of airspace.

Users provide data regarding the occurrence of various simulation events. These events include aircraft arrival/departure, airport configuration plan changes, and changes in weather conditions. Key outputs include aircraft travel times, flows and throughput capacity per unit of time, delays, and fuel consumption.

Level of Modeling Sophistication and Model Applications

SIMMOD is a widely utilized airport and airspace model all over the world, with about 300 registered users worldwide, 50-100 of whom are believed to be currently active. The model has also been the beneficiary of support and promotion by the FAA over the past decade.

The great majority of applications to date have dealt with the capacity and delay impacts of a variety of operational alternatives at airports. More recently, several studies dealing with reconfiguring regional or terminal airspace to reduce delays, reduce fuel consumption, or improve operational efficiency have also utilized SIMMOD.

As an aircraft delay and simulation model, SIMMOD is in the highest level of modeling sophistication of all capacity models. SIMMOD is a highly complex model which requires extensive time and resources to use in capacity projects.

Model Specifications

SIMMOD is written in SIMSCRIPT II.5 and maintained by FAA. Pre-processor and post-processor tools are written in Java (by third party provider like AirportTools and ATAC). SIMMOD can be run on windows as well as Linux. As an indication of speed of execution, a simulation of 24 hours of operation at a major airport takes about 1-3 minutes (single run).

Inputs and Data Availability

Inputs include traffic demand and fleet mix, route structures (both in the airspace and on the airport surface), runway use configurations, separation rules and control procedures, aircraft performance characteristics, airspace sectorization, interaction among multiple airports, and weather conditions. However, the principal input requirements are the specification of the network structure for the airfield and/or airspace simulated and the description of the traffic that will move on this network, including flight paths and paths between gates and runways.

Outputs

SIMMOD provides highly detailed statistics on each aircraft simulated. Outputs can be obtained on: aircraft travel times; traffic flows past specified points; throughput capacity per unit of time; delays by time of day and location on the airfield or in airspace, along with the immediate reason for each delay; and fuel consumption.

SIMMOD collects travel time and delay data for simulated arrival and departure operation and prints this information to an output file at the conclusion of each simulation iteration. Travel times and delays are reported by phase of flight during which they were incurred (e.g., on the ground or in the air). Delays in SIMMOD represent excess travel time incurred by flights because of their interactions with other aircraft in the system.

Model Limitations

The principal restrictive assumption in SIMMOD is that traffic must move on a pre-specified network of nodes and links according to pre-specified operating strategies or "rules of the road". In terms of conflicts between aircraft paths, SIMMOD is essentially an 1-dimensional model, checking for conflicts along the aircraft’s longitudinal path only, with no possibility of checking for lateral or vertical separation violations.

The principal perceived weakness of SIMMOD is that it is a "labor intensive" model whose users must undergo a significant amount of training. Moreover, to avoid several potential pitfalls, SIMMOD users must have a very good understanding of ATM and airport operations. For example, because SIMMOD is essentially a one-dimensional model care must be taken so that the network structure on which the traffic moves is based on sets of nodes and links with sufficient lateral and vertical separations to avoid the presence of undetected conflicts during the simulation. SIMMOD is not appropriate for use in smaller airports or studies where capacity is not an issue.

Much of the effort associated with setting up a SIMMOD simulation is, in fact, expended in developing the airspace and/or airfield network on which the traffic will move. For example, if a fan or trombone pattern is to be utilized to increase the efficiency of approach spacing and sequencing, all the possible alternative paths in the fan or trombone must be explicitly "programmed" as part of the network representation.

Table 2.2-17
SUMMARY OF SIMMOD MODELING APPROACHES

Capacity Factor/Issue	SIMMOD	Comments/Questions
Geometry		
1. Runway exits (arrival runway occupancy times)	■	Model computes runway occupancy time based upon a random draw for touchdown distance down runway, and aircraft de-acceleration model. Minimum stopping distance compared to available runway exits.
2. Runaway entrances design/ multiple entrance taxiways	■	Multiple runway entrances and intersection departures accommodated.
3. Departure staging and sequencing	■	Rules can be written to control the departure queue, and the model optimizes the departure sequence. Dynamically increase arrival separation to give priority to departing aircrafts.
4. Runway crossings	■	Arrival separation is adjusted dynamically to give priority to aircrafts waiting to cross runway. Random variable startup spool time can also be used to add time required to cross runway after starting from wait.
5. Parallel taxiway	■	Any types of parallel taxiways can be modeled.
Airline Factors		
6. Fleet mix	■	Model allows fleet mix to be part of user defined ground groups and airspace groups. You can then set group specific characteristic like min, nominal, max air speed, gate time, wake turbulence.
7. Daily distribution of aircraft activity	■	Works from an airline flight schedule. Model allows cloning of partial of full schedule.
Aircraft Performance		
8. Aircraft avionics equipage	■	Not considered
9. Pavement conditions/braking action	■	Yes (see runway exits above)

Table 2.2-17 *(page 2 of 2)*
SUMMARY OF SIMMOD MODELING APPROACHES

Capacity Factor/Issue	SIMMOD	Comments/Questions
10. Random variability	🟩	• Aircraft speeds and separations • Tow connect, push/power back times • Gate-occupancy times (for loading or unloading passengers) • Takeoff and landing roll distances • Lateness of flights • Hubbing schedule operations • Runway crossing times
Runway Use and ATC procedures		
11. Visual flight rules/visual approaches	🟩	VFR and IFR
12. Wake turbulence	🟩	Approach separation distances and departure separation times for user created aircraft type classes (for ex. small, large, B-757 and heavy).
13. Weather	🟩	Three classes VMC, MVMC, and IMC.
14. Multiple approach technology	🟨	Diagonal separations for dependent parallel approaches. Paired visual approaches.
15. Runway-specific fleet mix assignment	🟩	User-defined rules for aircraft classes and types allowed to use each runway.
Human Factors		
16. Controller workload	🟨	Model allows airspace links to be part of sector.
17. Voice communications	🟥	Not considered.
18. Random variability	🟩	In-trail separations.
Airspace Factors		
19. Departure fix restrictions	🟩	User-defined rules for departure fix restrictions by aircraft type or destination.
20. Neighboring airports	🟩	Multiple airports simulation.
21. Missed approaches	🟥	Not considered.

🟩 Model fully addresses capacity factor

🟨 Model partially or indirectly addresses capacity factor

🟥 Model does not address capacity factor

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ACRP 03-17

Evaluating Airfield Capacity

Appendix 3 to Final Report: ACRP Capacity Spreadsheet Model Validation

June 29, 2012

LeighFisher

in association with

Landrum & Brown

Wilbur Smith Associates

George Mason University

University of California, Berkeley

Presentation & Design, Inc.

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INTRODUCTION AND BACKGROUND

One of the objectives of the ACRP 03-17 Evaluating Airfield Capacity research was to develop a prototype model to estimate hourly airfield capacity improving on existing lookup tables, rules of thumb, and charts and nomographs. Additionally it was necessary to draw comparisons between the spreadsheet model capacity results to some other known sources of airfield capacity work. The results were compared to the following methods/results for the purpose of validating the spreadsheet model for reasonableness:

- FAA Advisory Circular 150/5060-5 tables
- *runway*Simulator project simulations
- 2004 FAA Benchmark Capacity Report

The FAA Advisory Circular 150/5060-5 (the AC) "Airport Capacity and Delay," provides guidance on calculating hourly capacity from using either the provided lookup tables or a series of interrelated charts and nomographs. The calculation of the results presented in the lookup tables are representative of the FAA's Airfield Capacity Model (ACM) for a set of airfield configurations and assumptions. Specifically, results used in this comparison were drawn from the tables identified as Figure 2-1 in the AC.

*runway*Simulator is a new simulation tool, which requires substantially less setup, calibration, data input, and user training in comparison to fast-time delay simulation models. *runway*Simulator performs time series airfield simulations and returns estimated hourly operational capacity levels based on a specific aircraft fleet mix and a set of separation minimums and other requirements. This simulation tool applies the generally accepted methodologies in aircraft spacing and adheres to the FAA guidelines on air traffic control requirements.

The 2004 FAA Benchmark Capacity report contains the airfield capacity estimations determined for the core U.S. Large Hub airports as calculated from simulation work performed by The Mitre Corporation under contract with the FAA. The methodology used by Mitre to estimate airfield capacity in the benchmarking study is observed to be a version of the ACM which was a predecessor to the development of the *runway*Simulator software program.

The validation process occurred over months of testing, revising, and retesting the model inputs and methodology against expected results by using accepted airport capacity rates and known operating levels at a number of U.S. airports. Additionally small airport capacity estimates were compared to expectations more focused on the advisory circular lookup tables.

The common airport examples evaluated were:

- SAN-San Diego International Airport (single runway)
- SJC-San Jose –Mineta International Airport (closely spaced dual parallel runways)
- LGA-New York LaGuardia International Airport (dual intersecting runways)
- FLL-Fort Lauderdale-Hollywood International Airport (dual runway portion only)

Airfield capacity evaluations were estimated for VMC and IMC weather conditions separately, but no overall capacities were evaluated and therefore weather data was not needed nor used in the validation of the spreadsheet model.

Similar aircraft fleet mixes were applied when comparing the spreadsheet model to the Advisory Circular tables and to specific runwaySimulator runs. In comparison to the Benchmark Capacity Report, the fleet mix was assumed to follow the average aircraft fleet mixes derived from operational information in the FAA ASPM database for each airport during the same timeframe as the capacity report.

Common to all of these models and the manner in which the results were achieved is the focus on two main objectives: aircraft separations and applicable requirements.

General assumptions in the spreadsheet model as to safety buffers and minimum separation standards were applied in a consistent manner and held constant for each model-model evaluation. The following set of assumptions list those commonly applied as default assumptions in the test cases performed with the spreadsheet model.

Primary or General Assumptions

Length of Common Approach: **7 nm**
Departure Hold Buffer: **10 seconds**

Arrival Runway Occupancy Time:
Small: **32 seconds** Large: **46 seconds** Heavy: **55 seconds**

Average Variance in Arrival to Arrival spacing: **18 seconds**

Departure Runway Occupancy Time:
Small: **34 seconds** Large: **46 seconds** Heavy: **51 seconds**

Average Variance in Departure runway clearance: **6 seconds**

Arrival to Departure Separation Minimum in VMC: **2 nm**
Arrival to Departure Separation Minimum in IMC: **2 nm**

Arrival to Arrival Separation Minimums:

VMC	IMC
Small-Small: **1.9 nm**	Small-Small: **3.0 nm**
Small-Large: **2.7 nm**	Small-Large: **4.0 nm**
Small-Heavy: **4.6 nm**	Small-Heavy: **6.0 nm**
Large-Large: **1.9 nm**	Large-Large: **3.0 nm**
Large-Heavy: **3.6 nm**	Large-Heavy: **4.0 nm**
Heavy-Heavy: **2.7 nm**	Heavy-Heavy: **5.0 nm**

Departure to Departure Separation Minimums:

VMC	IMC
Small-Small: **35 seconds**	Small-Small: **60 seconds**
Small-Large: **80 seconds**	Small-Large: **80 seconds**
Small-Heavy: **120 seconds**	Small-Heavy: **120 seconds**
Large-Large: **60 seconds**	Large-Large: **60 seconds**
Large-Heavy: **120 seconds**	Large-Heavy: **120 seconds**
Heavy-Heavy: **90 seconds**	Heavy-Heavy: **90 seconds**

Validation and Comparison Results Summary

1. Small Airports comparison using Advisory Circular lookup tables: (only)

The final results represent a 50% arrivals and 50% departures mix of operations. The total hourly capacity therefore represents a balanced flow or balanced operational mix. The comparisons were mainly performed on single runway airfield configurations which match the most common type of airfield where small general aviation or executive aircraft activity occurs.

Small Recreational Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 50%			VMC	IMC
Mix Index	0-20% (C+3D)	old AC	98	59
	100% Small-S	Spreadsheet	90	66

Small Executive Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 40%			VMC	IMC
Mix Index	21-50% (C+3D)	old AC	74	57
	25% Small-S, 50% Small-T, 25% Small+	Spreadsheet	74	62

2. Common Airport comparisons

It is assumed that the results should be comparable even though the fleet mix variables may be slightly different in each of the models reviewed. Furthermore, it is assumed that airfield configurations are consistent for comparisons with the 2004 Benchmark Capacity study.

SAN-San Diego International Airport (single runway)

San Diego International Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 0%			VMC	IMC
Mix Index	81-120% (C+3D)	old AC	55	53
	4% Small-S, 20% Small+, 67% Large-Jet, 9% Heavy	Spreadsheet	60	54
	Similar	rS	60	52
	Similar	Benchmark	58	50

SJC-San Jose –Mineta International Airport (closely spaced dual parallel runways)

San Jose International Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 0%			VMC	IMC
Mix Index	81-120% (C+3D)	old AC	105	59
	18% Small-S, 3% Small-T, 76% Large-Jet, 3% Heavy	Spreadsheet	68	48
	Similar	rS	68	50
	Similar	Benchmark	n/a	n/a

LGA-New York LaGuardia International Airport (dual intersecting runways)

LaGuardia International Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 0%			VMC	IMC
Mix Index	81-120% (C+3D)	old AC	76	59
	5% Small, 20% Large-TP, 70% Large-Jet, 5% Heavy	Spreadsheet	78	66
	Similar	rS	76	64
	Similar	Benchmark	78	74

FLL-Fort Lauderdale-Hollywood International Airport (dual runway portion only)

FLL is modeled more like two single runway models than a dual parallel model as the south runway is limited with aircraft type restrictions and ATC procedures not accounted for in using the general dual parallel airfield configuration in the advisory circular lookup tables.

Fort Lauderdale International Airport				
			Maximum Hourly Capacity	
Touch & Go's assumed to be 0%			VMC	IMC
Mix Index	81-120% (C+3D)	old AC	111	70
	12% Small, 83% Large-Jet, 5% Heavy	Spreadsheet	64	56
	Similar	rS	68	52
	Similar	Benchmark	62	54

Conclusions

The results shown in these tables comparing the ACRP spreadsheet model results to those from using runwaySimulator, the 2004 Benchmark Capacity Study and also the advisory circular lookup tables were observed to be acceptable and within a reasonable range.

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ACRP 03-17

Evaluating Airfield Capacity

Appendix 4 to Final Report: runawySimulator Testing and Validation

June 29, 2012

LeighFisher

in association with

Landrum & Brown

Wilbur Smith Associates

George Mason University

University of California, Berkeley

Presentation & Design, Inc.

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INTRODUCTION

The purpose of the testing and validation effort for the runwaySimulator was to its capacity predictions with empirical data. 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—Fort Lauderdale-Hollywood international Airport (FLL), Newark Liberty International Airport (EWR), LaGuardia Airport (LGA), and San Diego International Airport (SAN). These airports provide representative, busy, one- and two-runway airports where demand is at or near capacity during peak hours, but have other hours that are less busy. They also provide a sampling of dual parallel and intersecting runway conditions, and include aircraft taxiing across runways. Three visibility conditions—VMC, MVMC, and IMC are represented for each airport. Two different VMC configurations are tested for EWR and LGA, bringing the total test cases to 14.

In these test cases, the research team compared the *runway*Simulator outputs with observed data. The source of the observed data was the FAA's Aviation System Performance Metrics (ASPM) database. ASPM contains extensive operational data for major US airports, including all four considered in our tests. Much of the ASPM data is aggregated into quarter-hourly observations, by airport; such quarter-hourly 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. The demand includes all flights planned to arrive or take-off in a 15-minute period, as well demand from earlier periods that has yet to be fulfilled.

In addition to these quarter-hourly data, ASPM has data on individual flights, including departure and arrival airports, OOOI (Out Off On In) times, scheduled arrival and departure times, and aircraft type. For this study, we used the individual flight data to determine the fleet mix.

The research team obtained the foregoing data for each of the four airports considered in our test cases, covering the five-year period from 8/1/2006 to 7/31/2011. Using these data, two types of validation were performed. The first approach is to directly compare observed arrival and departure counts with the *runway*Simulator output. The second method is to use the data to estimate an econometric model, the results from which can be used to estimate a capacity which can be compared with the *runway*Simulator output. Most of our effort was focused on the first method, which is more straightforward and requires fewer assumptions. The second approach was more exploratory.

COUNT COMPARISONS—METHODOLOGY

The quarter-hourly data were filtered and aggregated to obtain observations that would be suifor comparison with *runway*Simulator output. For a given test case, the first step was to collect the observed arrival and departure counts and called rates for the associated airport, runway configuration, and weather condition. Next, the quarter-hourly observed counts were filtered and aggregated to obtain a set of hourly observations meeting the following criteria:

1. *Throughout the hour, the sum of the airport arrival rate and the airport departure rate is within the normal range observed for that case over the five year period.*

The purpose of this criterion was to eliminate observations for off-nominal conditions, such as non-functioning navigational aids, adverse weather in the terminal area, configuration transitions, an unusually unfavorable (or favorable) fleet mix, or reduced controller staffing. Controllers would respond to such conditions by changing the called rates, so the study team interpreted an unusually low or high rate as a signal of unusual airport or terminal area conditions.

2. *Demand throughout the hour was sufficiently high to justify the assumption that the airport is operating at or near capacity.*

The aim of this analysis is to compare observed operations counts with capacities predicted by *runway*Simulator. For this comparison to be meaningful, data must be drawn from periods in which demand is high enough so that counts are capacity-limited rather than demand limited. To take an extreme example, at most airports the counts at 3am do not reflect capacities, and thus cannot be compared with *runway*Simulator results.

To identify hours in which counts are likely to reflect capacity, observed count was plotted against observed demand for each hour that met the criteria for called rate applied in step 1. To avoid distortions from fluctuating demand, the demand variable was calculated as the minimum quarter-hour operational demand (arrival demand plus departure demand) over the hour. In the plots, count initially increases with demand and then levels off. Presumably, the count levels off once demand reaches a point where it is not limiting the throughput. In the subsequent analysis, we considered only those hours where demand was at or above this “saturation level.”

In some cases, the count begins to decline with demand above a certain level. Past studies reveal that this occurs because, in order to demand to reach such a high level, a queue must have built up from low throughput in prior periods. Thus, the high demand is because of unusually low capacity in previous periods, which often persists into the period being observed. In these cases, we also eliminated observations in which demand exceeded this “super-saturation level.”

3. *The fleet mix among the observations is fairly consistent.*

Fleet mix affects capacity because minimum required separations between consecutive operations depend upon the size categories of the aircraft. Fleet mix is therefore an input to *runway*Simulator and most other runway capacity models.

The hourly observations remaining in the data set after application of filters 1 and 2 could have widely varying fleet mixes. The next step was to identify a subset of the observations with a fairly consistent fleet mix. To do so, cluster analysis was used. Cluster analysis takes a set of observations (defined, in this context, by the shares of small, large, B757, and heavy aircraft) and partitions them into subsets that are similar.

There are a variety of clustering algorithms and methods for determining the proper clusters from the algorithm results. This analysis employed Ward's clustering algorithm for the clustering. This method starts with each observation as its own cluster, and then finds the pair of observations that is "closest"—has the most similar fleet mix—and combines these into a single cluster and computes the centroid of that cluster. The process is then repeated, except that the centroid calculated in step 1 is used in place of the two observations that were clustered in the first step. Thus in each step the number of clusters is reduced by one by joining two clusters whose centroids are most similar.

The next step in the clustering is to determine the appropriate number of clusters. Here, the primary basis for this was the pseudo-f statistic. This is a measure of the ratio of the variation between clusters to the variation within clusters. Ideally, if the pseudo-f is plotted against the number of clusters, there is a local maximum. The number of clusters associated with this maximum is then chosen is then used. In practice, the pseudo-f does not always have a local maximum; in these cases various other criteria—not least of them analysts' judgment—was used to choose the number of clusters.

The final step was to choose one specific cluster for subsequent analysis. The chosen cluster was simply the one containing the largest number of observations. The centroid associated with this cluster was used as input to *runway*Simulator, and the throughput values for observations in this cluster were compared with the *runway*Simulator predictions.

4. *Wind conditions did not appear to be significantly reducing throughput.*

As a final filter, the team examined the observations for the chosen fleet mix cluster to determine if high winds were a throughput-limiting factor. To do this, a scatter plot of count versus wind speed was constructed. If there was evidence of a fall-off in throughput above a certain wind speed, then observations above this wind speed were removed.

To illustrate the count comparison procedure just described, consider the case of EWR under visual metrological conditions with runway 22L used for arrivals and runways 22R and 19 used for departures. Figure 1 shows a histogram of combined arrival and departure rates per quarter hour. On the basis of this figure, only quarter-hours with rates between 20 and 24 are considered in subsequent analysis (step 1). Figure 2 plots throughput against demand. On the basis of this plot, only periods with minimum quarterly demand levels greater than or equal to 20 are selected (step 2). Table 1 shows results of the cluster analysis on fleet mix (step 3). It was found that the appropriate number of clusters was four. Of the four clusters, the second was has the largest number of observations.

Figure 1
HISTOGRAM OF TOTAL CALLED RATE PER QUARTER HOUR—EWR, VMC, 22L|22R,19

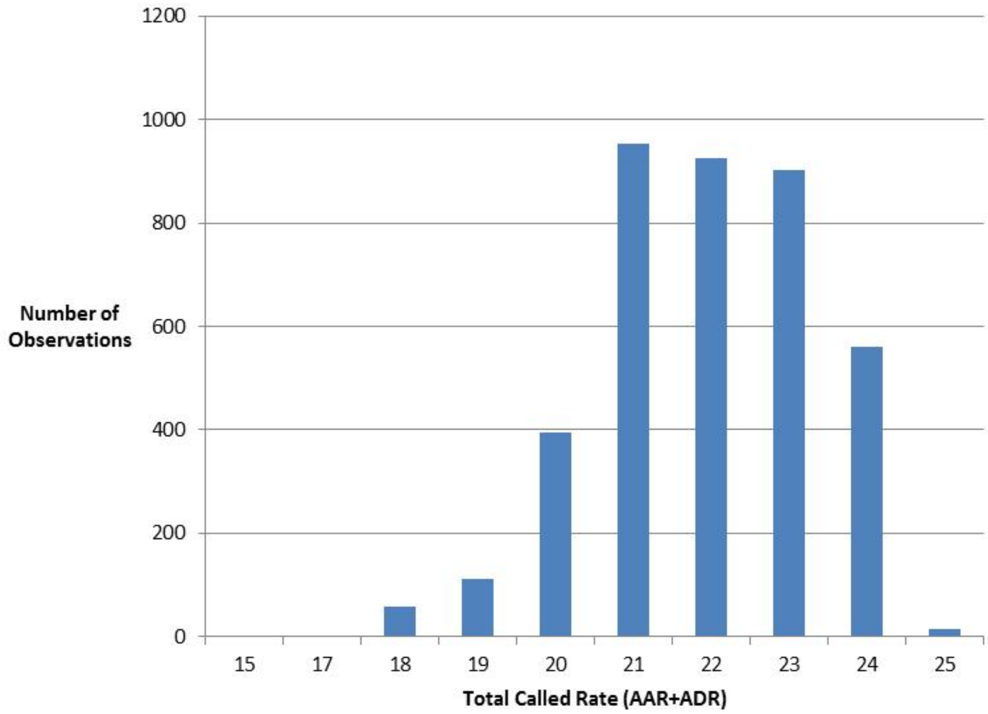


Figure 2
AVERAGE HOURLY THROUGHPUT VS. MINIMUM 15-MINUTE DEMAND, ROUNDED TO MULTIPLES OF FIVE EWR, VMC, 22L|22R,19

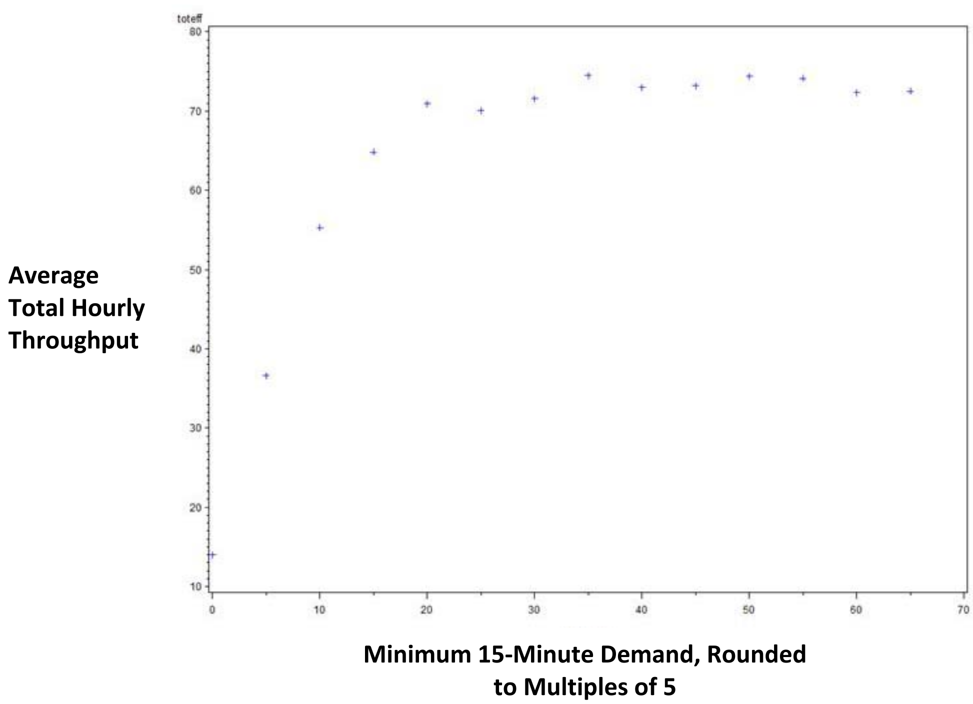
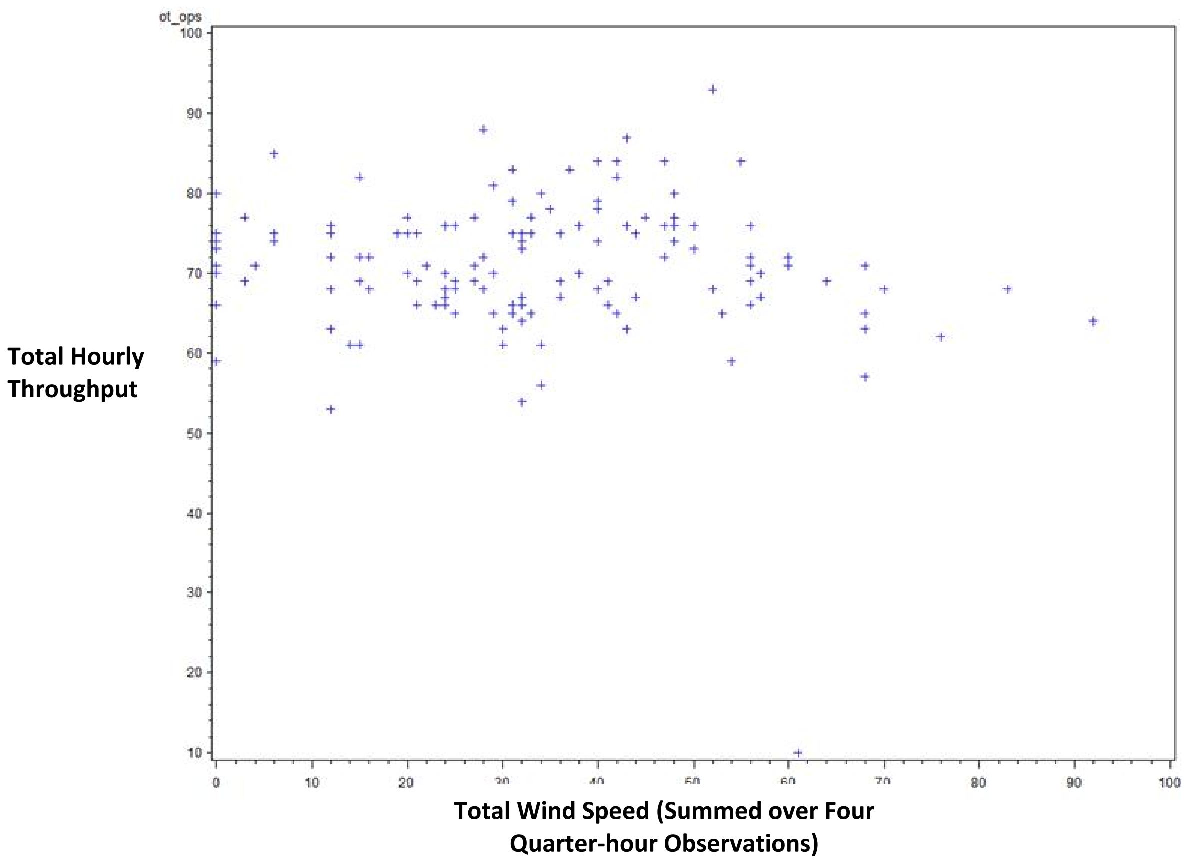


Table 1
FLEET MIX CLUSTER ANALYSIS RESULTS—EWR, VMC, 22L|22R,19

CLUSTER	_FREQ_	Small	Large	Heavy	B757
1	118	9.62%	80.19%	4.19%	6.00%
2	132	8.23%	72.60%	10.17%	9.00%
3	97	14.83%	70.33%	4.89%	9.95%
4	64	8.38%	64.79%	14.77%	12.07%

The fleet mix centroid for the second cluster (with 8.23% small aircraft, 72.6% large aircraft, etc) was used to determine the fleet mix inputs to *runway*Simulator. Finally Figure 3 shows, for observations in this cluster, a scatter plot of hourly count against wind speed (summed of four quarter-hourly observations). From this plot, it was determined that hours whose quarter-hourly wind speeds summed to more than 60 kts (an average of 15 kts) would be eliminated.

Figure 3
HOURLY THROUGHPUT VS. TOTAL WIND SPEED—EWR, VMC, 22L|22R,19



RESULTS

The hourly observations that resulted from this procedure were expected to reflect situations in which the observed operations count is comparable the airfield capacity as predicted by *runway*Simulator since:

- The called rates for these hours are within the normal range, indicating that the conditions are typical for the specified configuration and visibility condition;
- Demand appears to be sufficient to allow the airfield to operate at full capacity;
- The fleet mix for the observations is fairly consistent, with the average fleet mix used as input to *runway*Simulator;
- Throughput is not unduly affected by high winds.

One might thus expect that a Pareto plot of observed counts (arrival count versus departure count) would fall fairly close to the Pareto curve obtained from *runway*Simulator. In fact, however, there remained considerable scatter. To help compare the counts with the *runway*Simulator output, cluster analysis on the count data was performed. The objective was to find groups of observations whose counts of arrivals and departures were similar, and define centroids for these groups. Among the centroids found in this procedure, it was observed that in some cases the centroid arrival and departure counts were both less than the corresponding counts of another centroid. In this sense certain centroids are dominated by other centroids. Dominated centroids are assumed to reflect situations where airfield throughput was constrained by factors other than airfield capacity. The non-dominated centroid count values, on the other hand, are plausibly a reflection of airfield capacity, and are thus comparable with the output of *runway*Simulator.

The result of this analysis is a series of plots shown in Figures 4 through 17. Each plot contains the following information for each airport/visibility condition/runway configuration investigated:

- The Pareto curve from *runway*Simulator, based on the fleet mix obtained from the fleet mix cluster analysis as described above.
- The hourly arrival and departure counts for each observation belonging to the chosen fleet mix cluster.
- Centroids of the non-dominated clusters based on arrival and departure points.
- The most common called rates (airport acceptance rate for arrivals and airport departure rate for departures) for the observations whose counts are plotted.

Results for each airport are now discussed in turn. In addition to the plots, we will also present results for the count-capacity ratio (CCR). The CCR is a measure of the ratio between the empirical count corresponding to a cluster centroid and the capacity predicted by *runway*Simulator. The CCR metric is calculated using the following procedure. For each count centroid, we draw an imaginary ray from the origin through the centroid and the Pareto curve. We calculate total operations for the centroid and the point on the Pareto curve that intersects with this ray. The CCR is the ratio of the former count to the later count. A value over 100% implies that observed counts (as represented by the centroid) exceed capacity, while a value below 100% implies that the capacity exceeds the observed count.

Newark Liberty International Airport (EWR)

Observed counts at EWR are generally inside the Pareto curves generated by *runway*Simulator, as is generally the case for the other airports as well. Under VMC, CCRs range between 76% and 94%. The VMC plots suggest that the realized operational mix is more balanced than the capacities. For example, in the 11,22L|22R configuration maximum arrival counts and departure counts are both around 50, which is also the departure capacity. Although arrival capacity is about 67, the arrival counts never approach this number. In the case of 22L|22R,29, the departure capacity is greater but there is a sizable gap between observed departure counts and departure capacity.

Figure 4
ANALYSIS RESULTS—EWR, VMC, 11,22R|22L

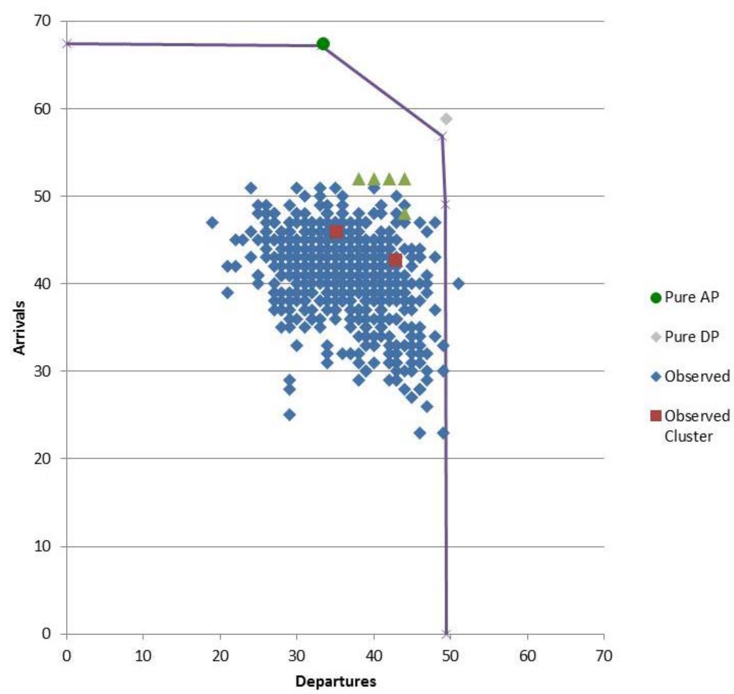
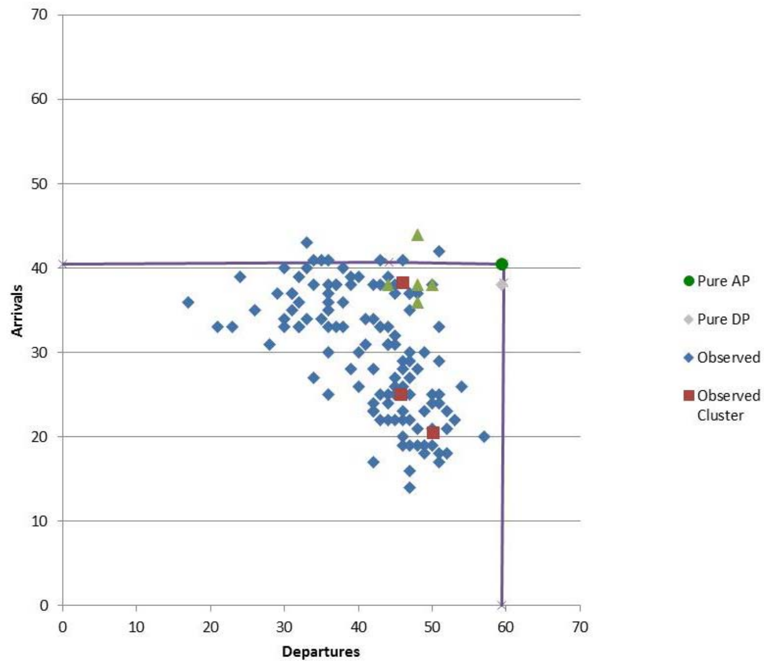


Figure 5
ANALYSIS RESULTS—EWR, VMC, 22L|22R,29



Called rates are well inside the Pareto curve for 11,22L|22R but much closer in the case of 22L|22R,29. Called rates are consistent with the Pareto curves with regard to which type of operation has the higher rate, but, as with the counts, the rates are more balanced than the capacities. Observed total counts are generally less than total called rates, although counts for individual operations types exceed associated called rates on some occasions.

Under the marginal VMC, 04R|04L, configuration, counts are again less than capacities, with CCRs between 84 and 90%. Called rates, in contrast, are at or outside the Pareto curve and well above the count centroids. Again, the counts and called rates are somewhat more balanced than the Pareto curve suggests would be possible. Under IMC (configuration 04R|04L) there is good agreement between count centroids and *runway*Simulator capacities. The called rates are somewhat outside the frontier in this case.

Figure 6
ANALYSIS RESULTS—EWR, MVMC, 4R|4L

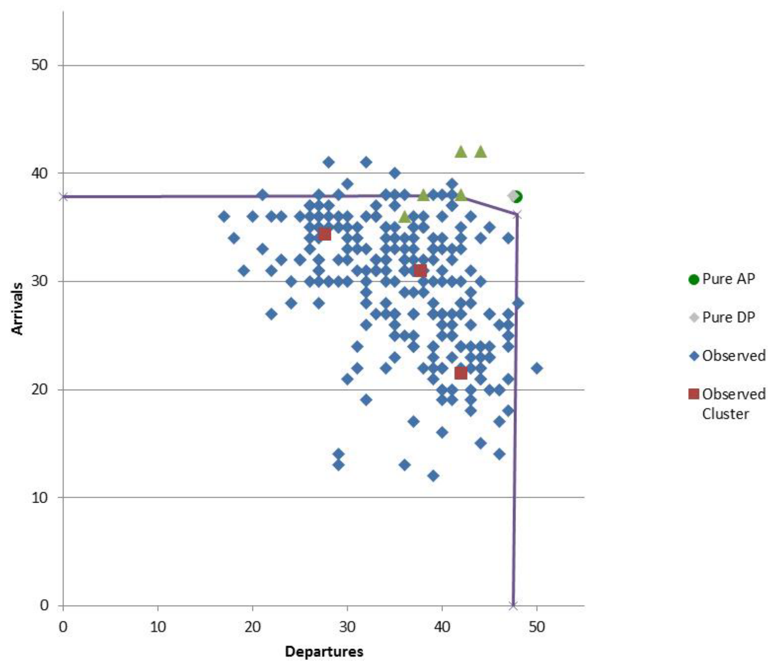
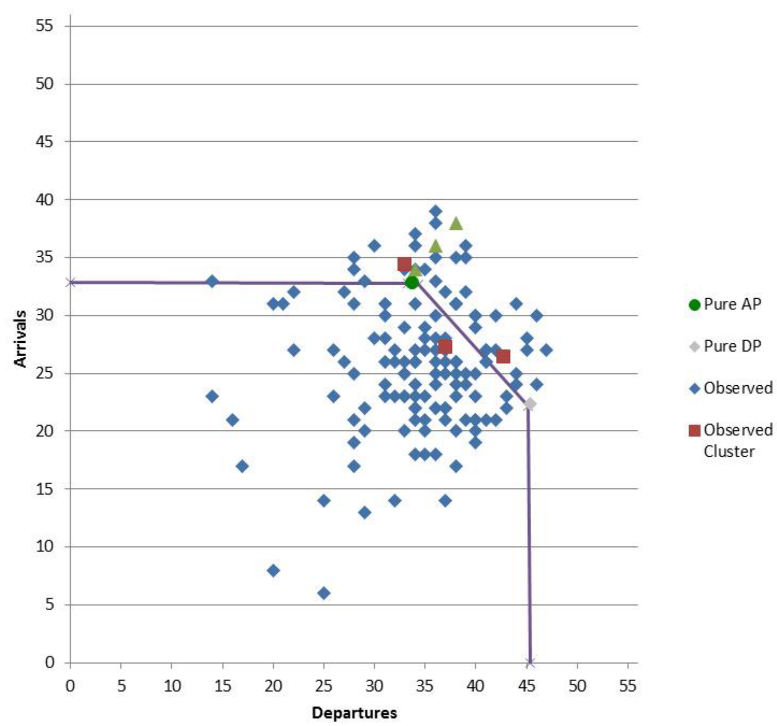


Figure 7
ANALYSIS RESULTS—EWR, IMC, 4R|4L



Comparing the called rates with the *runway*Simulator capacities for EWR, the rates appear to be more aggressive as the visibility (and hence the capacity) diminishes. This is consistent with FAA practice, which is to mitigate the disruptions caused by poor visibility conditions by pushing operations closer to the capacity limits.

New York LaGuardia (LGA)

The count centroids for LGA are, in general, very close to the Pareto curve, with CCRs of 103%, 103%, 99%, and 84%. The lower CCR comes from the VMC 22|13 configuration, which has the highest capacity of any of the cases. Indeed, the count centroids for the four LGA cases are very close to each other, even though the capacities vary. This may reflect the influence of slot controls in limiting demand, and therefore counts, at LGA. With the exception of the high capacity VMC 22|13 case, called rates at LGA fall slightly outside the Pareto frontiers.

Figure 8
ANALYSIS RESULTS—LGA, VMC, 22|13

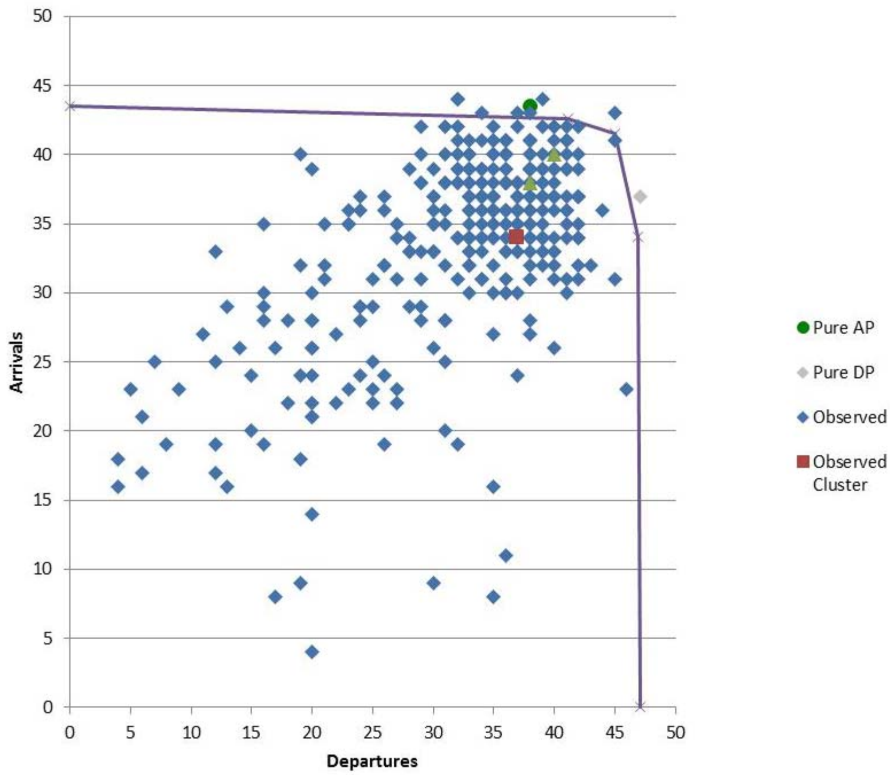


Figure 9
ANALYSIS RESULTS—LGA, VMC, 4|13

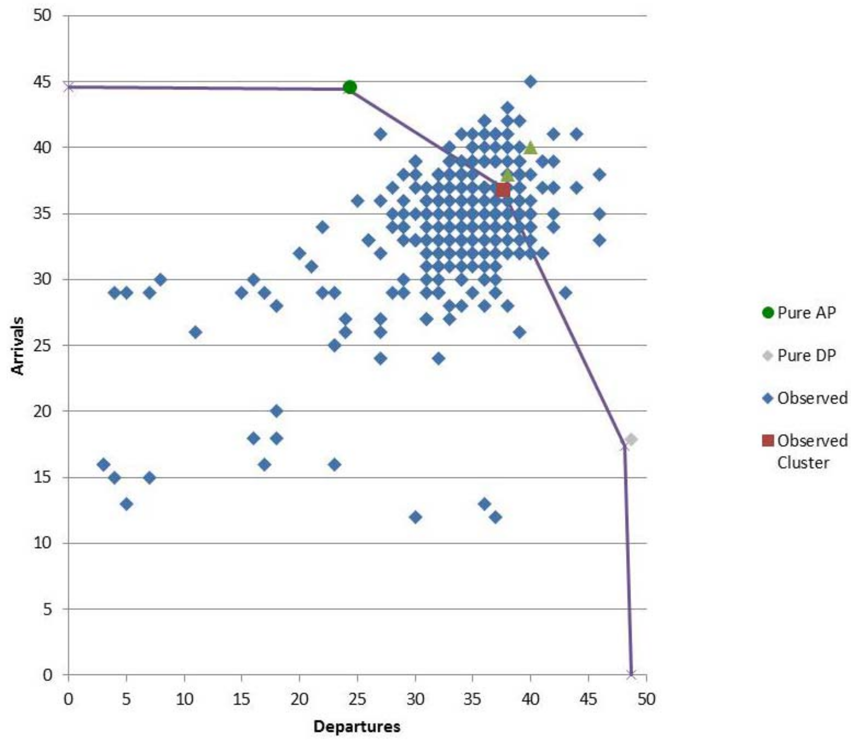


Figure 10
ANALYSIS RESULTS—LGA, MVMC, 4|13

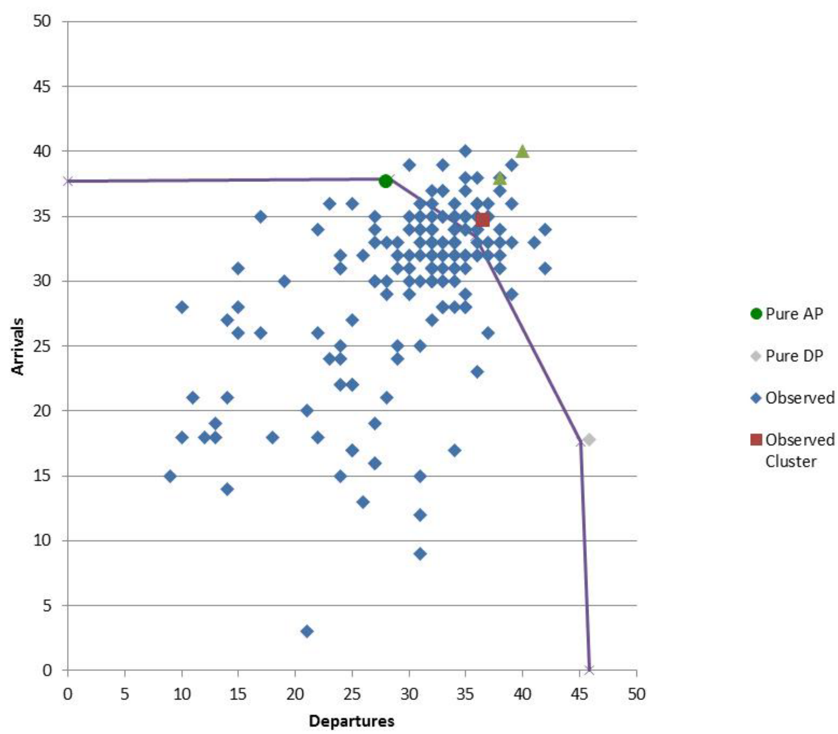
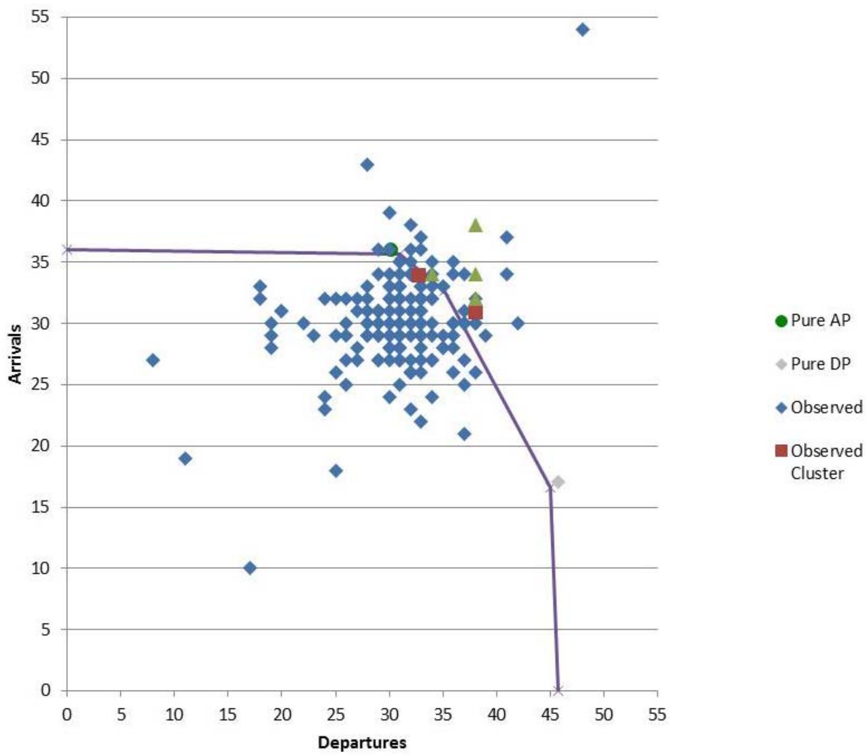


Figure 11
ANALYSIS RESULTS—LGA, IMC, 4|13



Fort Lauderdale-Hollywood International Airport (FLL)

FLL has sparse data because there are few time periods when demand features saturation levels. CCRs range from 66% to 86%. The called rates are consistently 42 for AAR and 40 for ADR, well outside the Pareto frontiers generated by *runway*Simulator. It appears that, despite the efforts to filter the data to include only high demand periods, in these cases the counts are demand limited. This may explain the use of constant rates across all three visibility conditions: if demand is consistently well below capacity, then the called rates are essentially irrelevant.

Figure 12
ANALYSIS RESULTS—FLL, VMC, 9L,9R|9L,9R

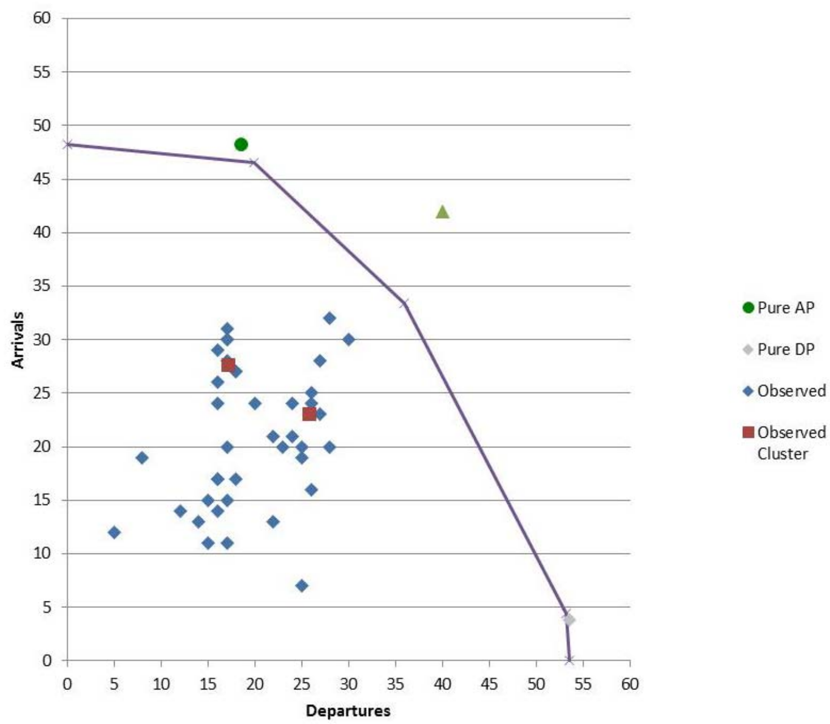


Figure 13
ANALYSIS RESULTS—FLL, MVMC, 9L,9R|9L,9R

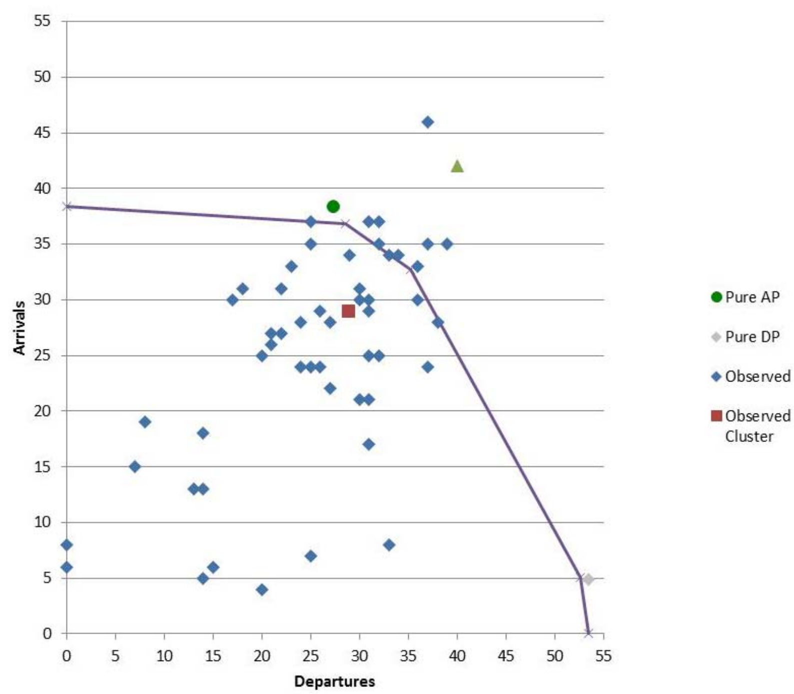
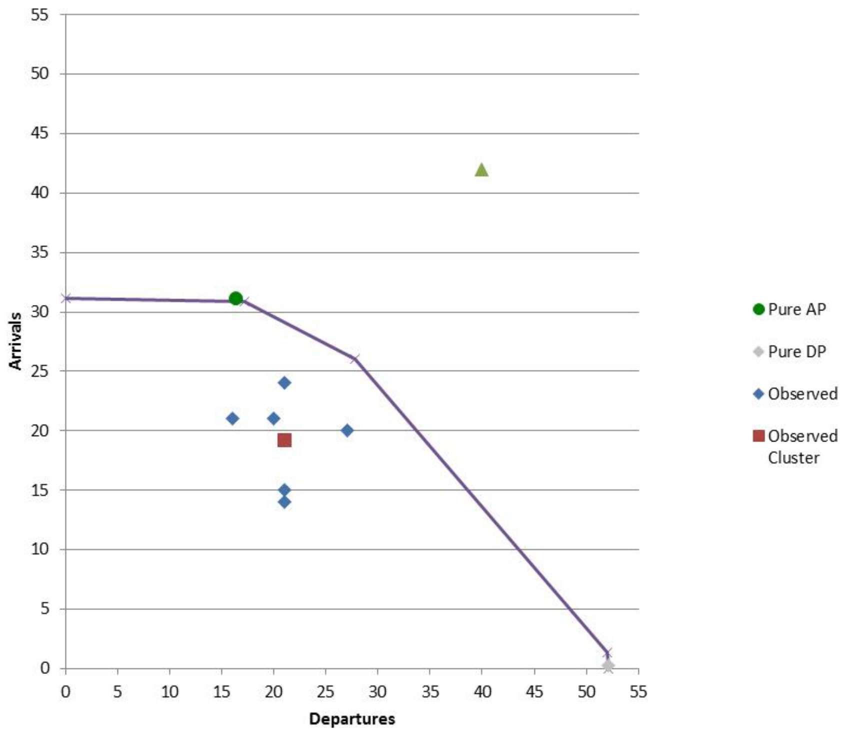


Figure 14
ANALYSIS RESULTS—FLL, IMC, 9L,9R|9R



San Diego International Airport (SAN)

CCR values for SAN range from 71% to 86%. Similarly to FLL, counts—even for periods identified as saturated—are well below capacities obtained from *runway*Simulator. The most common called rates are 24 for both AAR and ADR under all three visibility conditions. These called rates are within the Pareto frontier. They slightly exceed the count centroids under IMC, while being slightly less than the centroids under VMC and roughly equal under marginal VMC. Despite the modest differences between counts and called rates, it appears that the called rates act as limiting factors on the counts. Since the rates are within the Pareto frontier under all three visibility conditions, so are the counts.

Figure 15
ANALYSIS RESULTS—SAN, VMC, 27|27

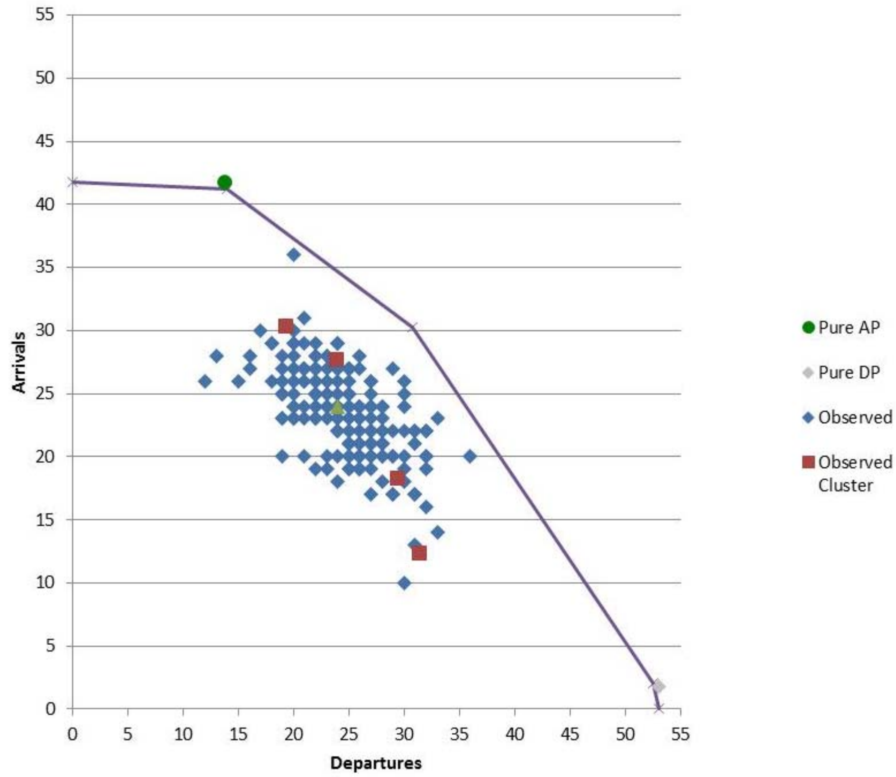
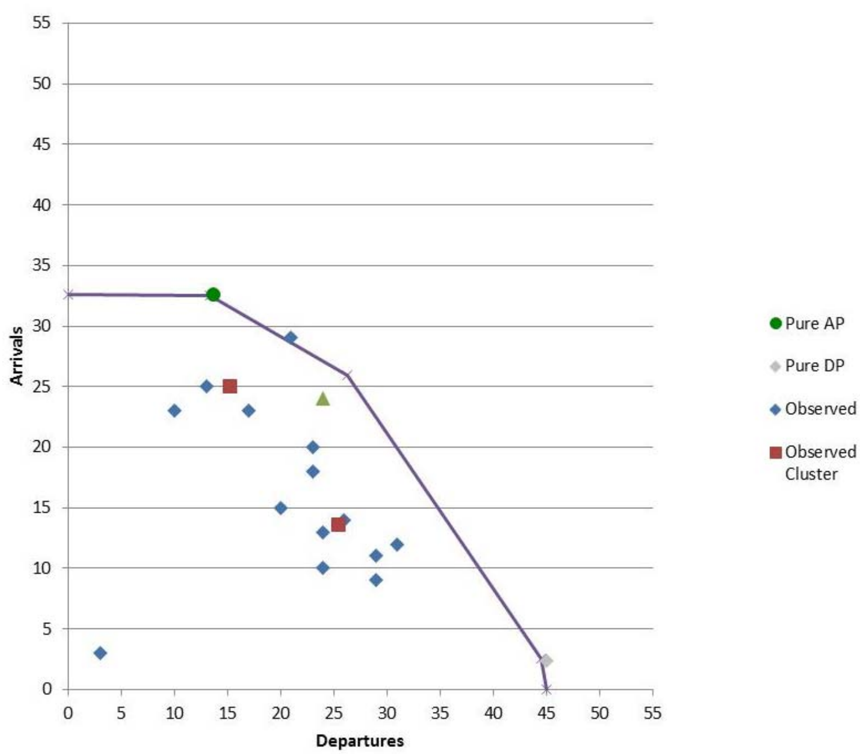


Figure 16
ANALYSIS RESULTS—SAN, MVMC, 27|27



ECONOMETRIC MODEL

Methodology

This approach is based on a statistical technique called censored regression. As applied, here, it is based on three main ideas:

- Observed throughput is the minimum of the demand and the realizable capacity.
- 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 sequencing, headway variability, the arrival-departures split, and airspace fix/runway loadings.
- The mean realizable capacity increases with demand, reaching the full capacity only as demand becomes very large.

The first idea is widely accepted and indeed 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 study. The ASPM count 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 probably because ASPM demand is based on flight plans, and, because of upstream disturbances, some of the demand does not materialize at the anticipated time. The demand may therefore need to be very large for it to be certain that enough flights will actually be available to arrive or depart at any given time period to make full use of the available capacity.

Based on the above assumptions, the research team developed a statistical model that used the ASPM count and demand data, including observations in which demand is quite low, and estimates the “limiting” capacity that is realized when demand becomes very large. The model was estimated on data for eight of the test cases—one VMC and one IMC case for each of the four test-case airports. The estimation approach takes into account that operational capacity varies with arrival/departure mix and is normally greatest when the mix is about even. The estimated limiting capacity values were then compared with the corresponding values obtained from *runway*Simulator.

The econometric model has the following form:

$$\log(Q_t) = \min\left[\log(D_t), \log(C_t)\right]$$

$$\log(C_t) = \beta_0 + \frac{\beta_1}{D_t} + \beta_2 \max\left[0, M_t - 0.5\right] + \beta_3 \max\left[0, 0.5 - M_t\right] + \varepsilon_t$$

Where the variables are defined as follows:

Q_t	Total operations count (arrivals + departures) in time period *t*.
D_t	Total operations demand (arrivals + departures) in time period *t*.
C_t	Total operational capacity (arrivals + departures) in time period *t*, a latent variable.
M_t	Arrivals count divided by total operations count time period *t.*
ε_t	The realization of a normally distributed random variable with mean 0 and standard deviation σ .
$\beta_0 ... \beta_3, \sigma$	Coefficients to be estimated.

The model treats capacity as a latent variable—one that is not directly observed—because in observations where the capacity exceeds the demand, the demand is determined by the count. In other cases the capacity is directly observed.

The capacity equation includes a baseline capacity determined by β_0 . The coefficient β_1, which we expect to be negative, captures the effect of demand on capacity. As demand becomes large, this term approaches 0, implying that realizable capacity approaches its maximum value only as demand becomes large.

The parameters β_2 and β_3 capture the effect of operational mix on capacity. Reviewing Figures 4-17, we notice that capacity is generally highest when the mix of arrivals and departures is roughly even. β_2 captures the loss in capacity as the mix shifts toward predominantly arrivals, while β_3 captures the effect of a growing departure dominance. Finally, ε_t is an error term that captures the variability in capacity that remains after the other effects have been controlled for. It is assumed to have a normal distribution with a mean of 0 and a standard deviation σ that is estimated from the data.

The model was estimated for eight of the 14 cases considered in the count comparison. The cases consisted on one VMC case and one IMC case for each of the four airports. Following the procedure of the count comparisons, the study team performed a cluster analysis on the fleet mix and chose the fleet mix cluster with the largest number of observations for subsequent analysis. The centroid fleet mix for this cluster was used as input for *Runway*Simulator, while the set of observations for this cluster formed the data set for estimating the econometric model. Since the econometric model can handle observations with low demand, for this analysis we did not filter the observations to include only high demand periods.

RESULTS

Estimation results appear in Table 2. In general, the estimates have high t-statistics, indicating low standard errors and high significance, and have the expected sign. In particular, the estimates for β_1 are negative in all but one case. Since the β_1 term varies inversely with demand, the negative sign indicates that as demand increases so does maximum throughput, albeit in a concave manner so that at the limit the β_1 term approaches 0. The β_2 and β_3 terms are also negative in almost all cases, implying that as the mix of operations become more uneven, the capacity is reduced. Finally, the results for β_0 imply that capacity at a given airport is higher under VMC, as expected. Note that the β_0 values are not capacities per se, but their natural logarithms.

Results are compared with *runway*Simulator predictions in Table 3. The econometric capacity presented in Table 2 is calculated as $\exp(\beta_0)$ and represents the median capacity when demand is high enough to ignore the effect of β_1 and when the operational mix is evenly divided between arrivals and departures, so that the terms involving β_2 and β_3 can also be ignored. Capacities estimated from the statistical model average about 4 ops/hr—or 5%--greater than the *runway*Simulator predictions for the 50/50 operational mix. Considering all eight test cases, mean absolute error was 10 ops/hr. Excluding FLL, which has poor results because of limited fleet mix data, the error drops to 7 ops/hr. The correlation between the statistically estimated and *runway*Simulator generated capacities was 0.79 including FLL, and 0.87 excluding it. In general, therefore, the econometric model results are fairly consistent with those from *runway*Simulator. However, they also imply that realizable capacity does not reach *runway*Simulator predictions until demand reaches the level where the effect of the β_1 term can be ignored. For example, in the case of the EWR IMC 4R|4L, the ultimate capacity as shown in Table 2 is 72 ops/hr. At a demand of 100 ops/hr, however, the predicted capacity, calculated as $\exp\left(\beta_0 + \beta_1/100\right)$ is 58, about 20% less than the ultimate capacity and well below the assumed demand of 100 ops/hr.

Table 2
ESTIMATIONS RESULTS FOR ECONOMETRIC MODEL

Airport	WC	Configuration		β_0	β_1	β_2	β_3
EWR	VMC	11,22L|22R	Estimate	**4.57**	**-21.6**	**-0.601**	**-1.49**
			t-statistic	**707**	**-35.2**	**-12.3**	**-23.9**
	IMC	4R|4L	Estimate	**4.27**	**-21.8**	**-0.987**	**-0.41**
			t-statistic	**300**	**-17.3**	**-5.88**	**-3.19**
LGA	VMC	4|13	Estimate	**4.44**	**-19.8**	**-1.52**	**-1.3**
			t-statistic	**636**	**-29.6**	**-17.8**	**-16.9**
	IMC	4|13	Estimate	**4.16**	**-9.44**	**-2.01**	**-1.72**
			t-statistic	**219**	**-17.1**	**-10.6**	**-4.69**
FLL	VMC	9R,9L|9R,9L	Estimate	**4.45**	**-26.2**	**-0.253**	**-0.0707**
			t-statistic	**832**	**-105**	**-7.17**	**-2.14**
	IMC	9R,9L|9R,9L	Estimate	**3.53**	6.85	**-3.6**	-1.38
			t-statistic	**17.5**	0.98	**-4.57**	-0.89
SAN	VMC	27|27	Estimate	**4.2**	**-18.7**	**-0.277**	**-0.271**
			t-statistic	**464**	**-54.7**	**-4.58**	**-5.94**
	IMC	27|27	Estimate	**4.19**	**-22.9**	0.0645	-0.79
			t-statistic	**92**	**-16.9**	0.41	-0.98

Note: Estimates in bold are significant at 5% level.

Table 3
COMPARISON OF CAPACITY ESTIMATES FROM *RUNWAY*SIMULATOR AND ECONOMETRIC MODEL

		Runways		Capacity	
Airport	**WC**	**Arrival**	**Departure**	***Runway*Simulator**	**Econometric Model**
EWR	IFR	04R	04L	65	72
EWR	VFR	11,22L	22R	97	97
FLL	IFR	9L	9L,9R	53	34
FLL	VFR	9L,9R	9L,9R	67	85
LGA	IFR	4	13	68	64
LGA	VFR	4	13	74	85
SAN	IFR	27	27	53	66
SAN	VFR	27	27	61	66

CONCLUSIONS

In this section, we have compared observed operational counts with capacities predicted by *runway*Simulator. Prior to making these comparisons, we filtered and analyzed the data so that so as to make it as comparable with the *runway*Simulator model as possible. Despite this, observed counts, even when drawn from busy periods featuring normal operating conditions, are found to be generally below capacities calculated by *runway*Simulator. This difference does not mean that the model is wrong, but rather than runway capacity is not the only factor limiting realized throughput (as observed in the ASPM data based on quarter-hourly and hourly throughput values). As a rule of thumb, capacities calculated by *runway*Simulator should be reduced by 15 percent to approximate the actual counts that are representative of normal 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 slightly exceed, on average, the capacity estimates from the *runway*Simulator. In this latter case, one can say 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 from the statistical model. However, it would be rare to observe such throughput in practice, because demand rarely (if ever) meets the level that such throughput rates could be sustained on a consistent basis.