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7. Author(s) L.O. Higgins, Project Manager P.Mpontsikaris*MIT(ContractDOT/TSC-77)		8. Performing Organization Report No. DOT-TSC-FAA-71-7
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15. Supplementary Notes *Service Technology Corporation Cambridge, Mass. 02142		

16. Abstract Approximately two hundred reports were identified as describing Air Traffic Control (ATC) modeling and simulation efforts. Of these, about ninety analytical and simulation models dealing with virtually all aspects of ATC were formally evaluated. The bibliography lists all the reports identified. There is an introduction to, and a summary of the evaluation effort as of this publication. The summary also contains a preliminary indication of which models may be of value for ATC concept evaluation; specifically traffic flow, safety and system loading aspects of proposed concepts. The remainder of the document is a catalog of the written evaluation of the ATC models. The models are divided into seven categories: (A) Airport Surface Traffic, (B) Runway, Departure/Arrivals, (C) Terminal Area, (D) Enroute, (E) ATC Systems (and miscellaneous), (F) Cost-Effectiveness Models, and (G) Safety Related Models. The catalog will be updated periodically.

17. Key Words	18. Distribution Statement
•Air Traffic Control (ATC) •Modeling and Simulation of ATC •Evaluation of ATC Models	Unclassified — Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

INTRODUCTION

The objective in FAA Project Planning Agreement FA06 is to develop models of all significant aspects of the NAS and the air traffic control system. The objective of this modeling program is to evaluate the influence of procedural and hardware modifications on system performance and safety.

In partial support of this objective, previously developed models of air traffic and air traffic control were reviewed and evaluated. The results of this effort are contained in this document. A catalog of evaluations, containing a separate evaluation of each model was prepared by MIT under contract number DOT-TSC-77. The models are categorized and are evaluated with respect to criteria which are explained in the Users' Guide. The catalog should be a valuable tool for both those who wish to develop new models and those who wish to perform analyses with the aid of proven models. In the final analysis, however, there is no substitute for reading the original reports. This document should be considered primarily a catalog of what is available and a guide to more detailed information.

It is realized that some models may have been overlooked in this review. Some models listed were not received in time for evaluation. Any additions, corrections or recommendations should be addressed to:

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SUMMARY: A PRELIMINARY ASSESSMENT OF MODELS AVAILABLE FOR ATC CONCEPT EVALUATION

Based on the information contained in the catalog, a preliminary assessment was made of the utility of the various models for evaluating the effects of proposed concepts on the traffic flow, safety and loading aspects of the air traffic control system.

For the purposes of concept evaluation, it is felt that a hierarchy of models, such as that indicated in Fig. 1, is necessary. Figure 1 is not a flow diagram but rather a static chart showing the possible geographical levels for which evaluation of such characteristics as traffic flow, safety and system loading may be meaningful. For example, there would be a relationship between a model which calculates oceanic flow rate and a model which calculates collision probability as a function of separation standards, etc. The same model may be used for either purpose. However, our purpose here is to identify all of the models which may be useful for calculating any of the particular measures indicated in Fig. 1, without regard to interrelationships.

The models which were evaluated are listed in summary form in Table 1. The general utility of the model with respect to the needs of this project for traffic flow evaluation, for safety evaluation, or for system loading evaluation, is indicated by an index number (1, 2, or 3). The numbers are not meant to imply that one model is "better" than another. They are subjective ratings derived from the evaluations described in this document.

If a model is not rated at all, it is for one of the two following reasons: (1) the features of the model are completely incorporated in a more inclusive and/or more recent model, or (2) the model is not applicable for directly calculating any of the measures indicated in Fig. 1. This, of course, eliminates some algorithms.

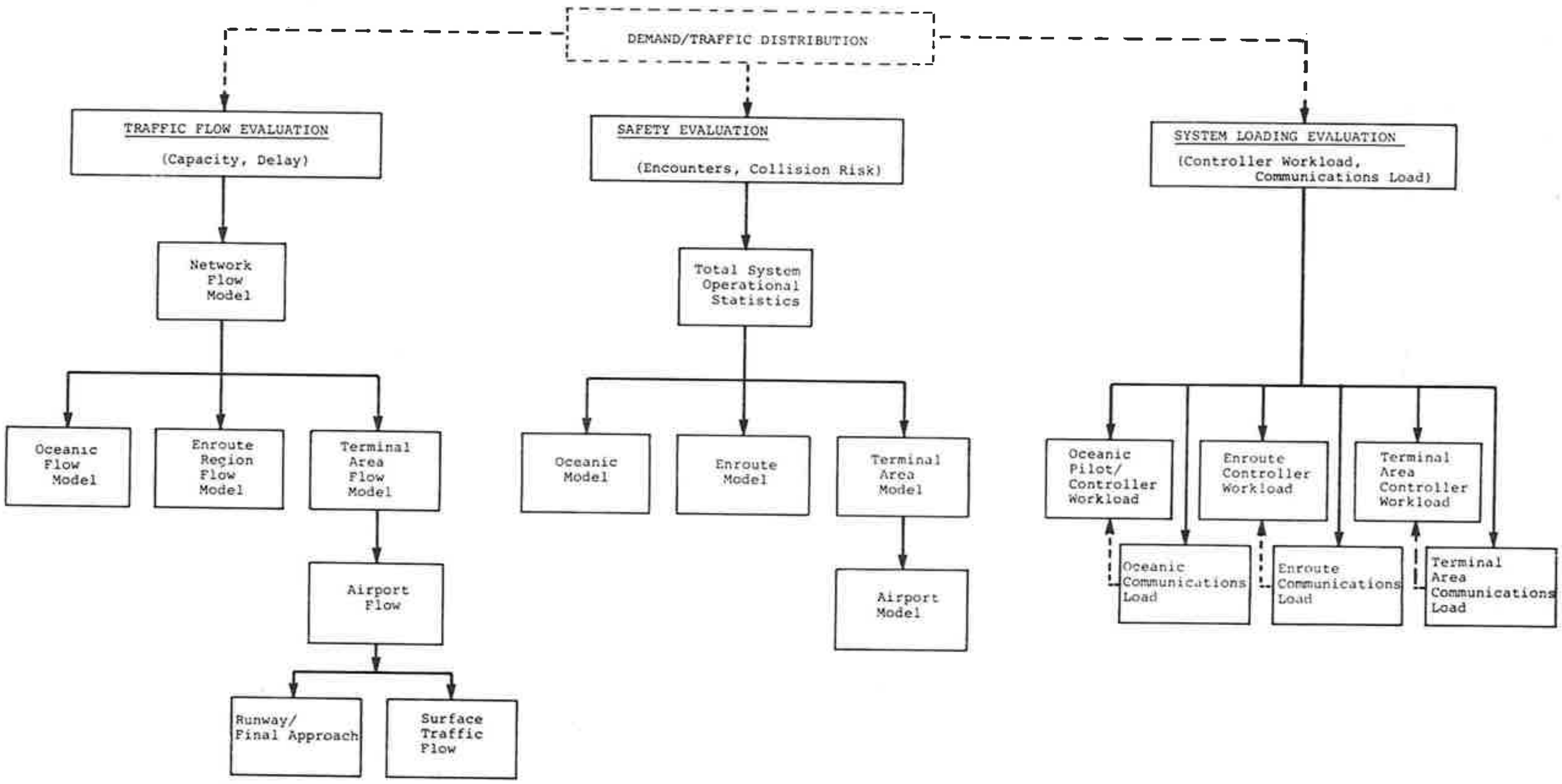

Figure 1. - ATC Concept Evaluation Models

The models which are rated in the table are generally limited to the types which are indicated by the top two levels, and to some extent the third level, of Fig. 2. This figure was taken from a brochure prepared by the Autonetics Division of North American Rockwell.

TSC intends to continue this cataloging and evaluation as part of PPA OS204 during FY72.

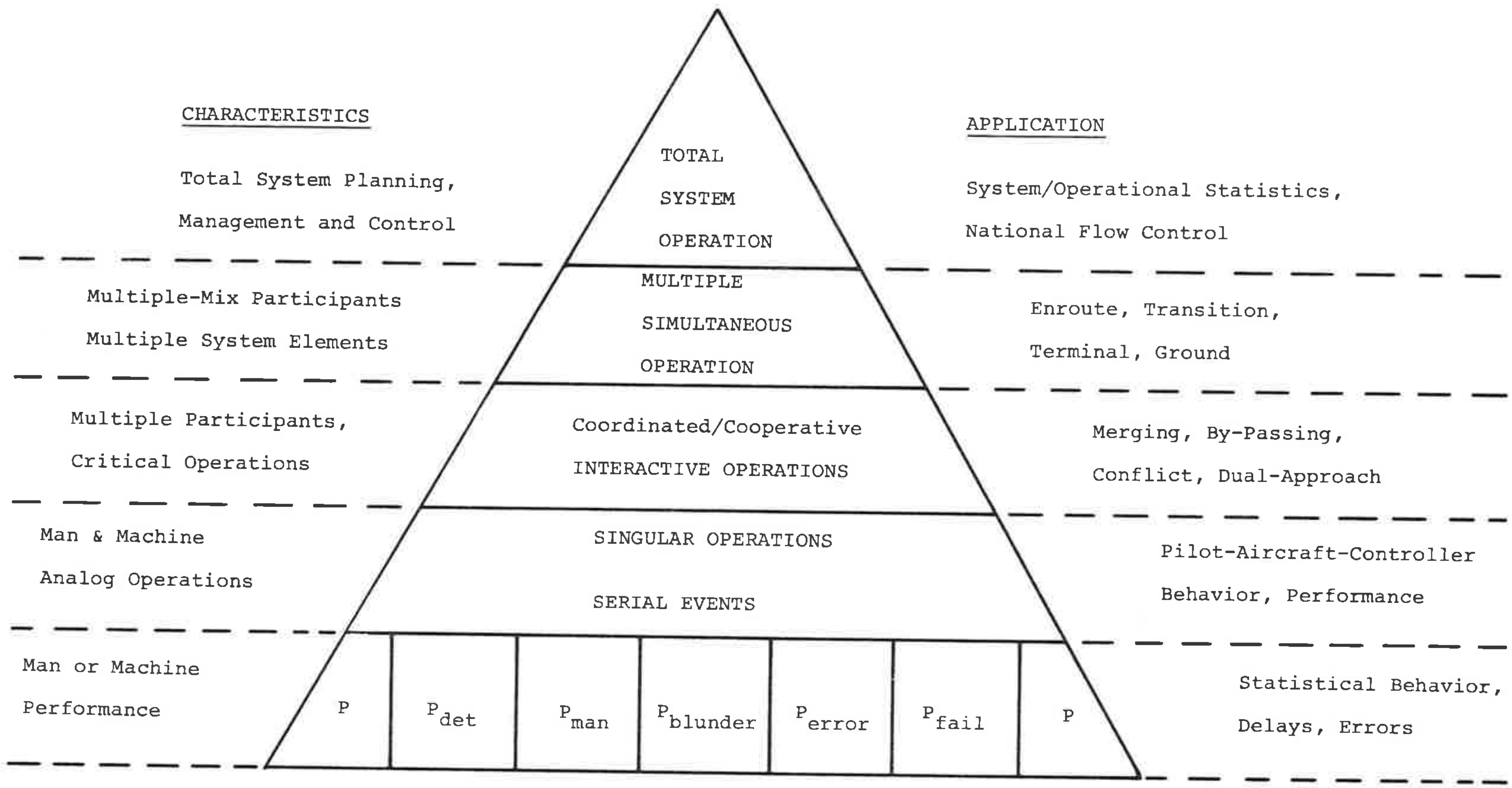

Figure 2. - Model Scope

TABLE 1.-SUMMARY OF EVALUATED MODELS

CATEGORY A: AIRPORT SURFACE TRAFFIC MODELS

Author	Title	Type*	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow**	Safety**	System Loading**
Dowe, E.J.	A Method for Computer Simulation of Airport Surface Traffic (A-1)	P,S	?	Capacity, Delay	Airport, Surface Traffic (3)		
Hall, S.	A Simulation of the Airside Traffic at an Airport (A-5)	P,S	UNIVAC-1108	Delay	Airport (2)		
Horonjeff, R., et. al.	A Mathematical Model for Locating Exit Taxiways (A-2)	P,A	LGP-30	Capacity			
Joline, E., et. al.	Simulation Model ASM-2 (A-3)	P,S	IBM 360-85	Capacity, Delay	Airport (1)		
Tucker, J. and Huggett, J.	A Preliminary Investigation into the Taxiway Congestion Problem (A-4)	P,S	?	Capacity, Delay	Surface Traffic (3)		

*P = Probabilistic, D = Deterministic, S = Simulation, A = Analytic
**Refer to Figure 1

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY B: RUNWAY – FINAL APPROACH MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Baran, G.	Airport Capacity Analysis (B-1)	D,A	—	Capacity			
Baran, G., et. al.	Approach Airspace and Runway Capacity Parametric Sensitivity Analysis (B-2)	P,A	—	Capacity	Runway(2)		
Baran, G., et. al.	Runway Capacity Augmentation Study (B-3)	P,A	—	Capacity			
Blumstein, A.	An Analytical Investigation of Airport Capacity (B-4)	P,A	—	Capacity, Delay	Runway(1)		
Blumstein, A.	An Analytical Investigation of Airport Capacity (B-5)	P,A	—	Capacity, Delay	"		
Faison, W.	An Analysis of a Procedure for Conducting Instrument Approaches to Parallel Runways Spaced Less than 5000 Feet Apart (B-6)	P,A	—	Risk		Airport(1)	

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY B: RUNWAY – FINAL APPROACH MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Harris, R.	Models for Runway Capacity Analysis (B-7)	P,A,S	IBM 360-?	Capacity, Delay	Runway(1)		
Harris, R.	Models for Runway Capacity Analysis (B-8)	P,A,S	IBM 360-?	Capacity, Delay	Runway(1)		
Holland, F., et. al.	Investigation of Computer Aided Control Concepts in the Terminal Area (B-9)	P,A	IBM 7090	Capacity			
Hooten, H., et. al.	Operational Evaluation of Airport Runway Design and Capacity (B-10)	P,A	IBM 7090	Capacity, Delay	Runway(2)		
Hosford, J.	Simulation by Incremental Stochastic Transition Matrices (B-11)	P,S	IBM 360/65	Delay	Runway(3)		
Keenan, J. and Barnsby, A.	Functional Description of Basic Terminal Approach Simulation Model (B-12)	S	IBM 7094		Terminal(3)		
Koetsch, J.	Combined Landing and Take-Off Capacity of a Single Runway (B-13)	P,A	—	Capacity			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY B: RUNWAY – FINAL APPROACH MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Mallen, G.	A Digital Simulation of Airport Runway Utilization Comparing the Effects of Alternative Queue Disciplines and Various Types of Traffic Input (B-14)	P,S	Mercury	Delay			
Marks, B.L.	Digital Simulations of Runway Utilization (B-15)	P,S	Mercury	Delay			
Meisner, M.	Analysis of Alternatives for Increasing Runway Capacity and Reducing Terminal Delays (B-16)	P,A	—	Capacity, Delay			
MITRE Corp.	Traffic Generator and Basic Approach and Landing Simulation (B-17)	P,S	IBM 7094, 360		Terminal(3)		
National Bureau Standards (Goldman, et. al.)	Analysis of a Capacity Concept for Runway and Final-Approach Analysis (B-30)	P,A	—	Capacity	Runway(1)		
Odoni, A.R.	An Analytic Investigation of Air Traffic in the Vicinity of Terminal Areas (B-18)	P,A	—	Capacity	Runway(1)		
Odoni, A.R.	An Analytic Investigation of Air Traffic in the Vicinity of Terminal Areas (B-19)	P,A	?	Capacity, Delay	Runway(1)		
Oliver, R.M.	Delays to Aircraft Serviced by the Glide Path (B-20)	P,A	—	Delay			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY B: RUNWAY – FINAL APPROACH MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Oliver, R.M.	Delays in Terminal Air Traffic Control (B-28)	P,A	—	Delay			
Ottoson, H.I.	A Theoretical Determination of the Probability of a Missed Approach Along the Glide Path (B-21)	P,A	IBM 709	Capacity	Runway(3)		
Ottoson, H.I.	Sensitivity of a Terminal Area Control Concept to Uncertainties in Control Information (B-22)	P,S	?				
Pardee, R.S.	Analysis of Sequencing Methods (B-29)	P,S	IBM 709	Capacity, Delay			
Raisbeck, G., Koopman, B., et. al.	A Study of Air Traffic Control System Capacity (B-23)	P,A	?	Delay	Runway(3)		
Ratcliffe, S.	Aircraft Sequencing, Parallel Landings and the TMA Route Structure (B-24)	P,A	—				
Simpson, R.W.	An Analytical Investigation of Air Traffic Operations in the Terminal Area (B-25)	P,A	—	Capacity (VFR)	Runway(1)		
Taylor, W., et. al.	Theoretical Minimum Separation of Parallel Runways (B-26)	P,A	—	Risk		Airport(1)	
Warskow, M., Wisepart, I.	Capacity of Airport Systems in Metropolitan Areas - Summary; Methodology of Analysis; Validation (B-27)	P,A	—	Capacity	Airport(1)		

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY C: TERMINAL AREA MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Carlin, A., Park, R.	A Model of Long Delays at Busy Airports (C-11)	D,A	(JOSS)	Delay, Cost	Airport(3)		
Faison, W., et. al.	Analytical Study of Air Traffic Capacity in the New York Metropolitan Area (C-12)	P,A	—	Capacity			
Hall, S.	A Simulation of the Airside Traffic at an Airport (C-14)	P,S	UNIVAC-1108	Delay	Airport(2)		
Ingram, G.W.	The Terminal Air Traffic Scheduling Model (C-7)	P,A	?				
Jackson, A.S., et. al.	A Fast Time Simulation Model of Automated Terminal Area ATC Systems (C-2)	P,S	IBM 7090				
Jolitz, G.D.	Flow Control - An Investigation of a Technique for Predicting Demand and Service at the Terminal Facility (C-10)	P,A	IBM 7090	Demand (Predicted)			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY C: TERMINAL AREA MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Ottoson, H.I.	An Investigation of the Expected Magnitude of Control Errors in the TASC I System Transition Area (C-6)	P,A	IBM 709	Gate Error			
Ratner, R.S.	A Methodology for Evaluating the Capacity of Air Traffic Control Systems (C-3)	S	?	Capacity, Delay, Workload	Terminal(2)		
Short, E., et. al.	DELCAP: A Simulation for Estimating Terminal Area Throughputs and Delays (C-5)	P,D,S	UNIVAC-1108	Capacity, Delay	Terminal(1)		
Simpson, R.W.	An Analytical Investigation of Air Traffic Operations in the Terminal Area (C-1)	P,D,S	IBM 7094		Terminal(1)		Terminal Communications (1)
Simpson, R.W.	An Analytical Investigation of Air Traffic Operations in the Terminal Area (C-8)	P,A	—	Capacity			
Simpson, R.W.	An Analytical Investigation of Air Traffic Operations in the Terminal Area (C-9)	P,A	—	Capacity			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY C: TERMINAL AREA MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Slattery, H.F.	New York Air Traffic Capacity Study (C-4)	S (Real time)	(Real time)	Capacity			
Warskow, M.A.	Techniques Useful in the Assessment of Terminal Area Design and Capacity (C-13)	P,A	?	Capacity, Workload (Complexity)			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY D: ENROUTE TRAFFIC MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Abbott, M.R.	Digital Simulation Study of an Idealized Model of a Computer-Controlled Procedural Free Route System for North Atlantic Air Traffic (D-1)	P,D,S	Mercury	Capacity	Oceanic(1)		
ARCON Corp.	Air Traffic Control Theory and Design (D-2)	P,D,A	—	Encounters			
ARCON Corp.	System Analysis of the North Atlantic Air Traffic Complex (D-3)	P,D,A	—	Capacity, Position Error	Oceanic(2)		
ARCON Corp.	Study of Future Oceanic Aviation Support Systems (D-4)	P,D,A	?	Cost, Risk Level, Communications Load			Oceanic Communications(1)
deBarbeyrac, J., and Villiers, J.	Air Traffic Control Procedures in a Parallel Track System (D-5)	P,A	—	Number of Control Interventions			
Medeiros, M.F., Jr.	Enroute Air Traffic Flow Simulation (D-6)	S	MULTICS T/S		Network(3) Enroute(3)		Enroute Workload(3)
Reich, P.G.	Analysis of Long Range Air Traffic Systems III - Separation Standards (D-7)	P,A	—	Collision Risk		Oceanic(1)	
Warskow, M.A.	TRANSAIR (D-8)	P,S	IBM 360-40	Workload (Complexity)			Enroute, Terminal Workload(1)

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY E: ATC SYSTEMS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Arad, B., et. al.	Control Load, Control Capacity and Optimal Sector Design (E-1)	D,A	--	Workload			
Barnsby, A.E.	Airspace Model Description (E-2)	P,S	?		Network (3) Enroute (3)		
Burlin, C.W.	Air Traffic Control Simulation Model Exploratory Study (E-3)	D,S	IBM 360/85	Delay, Conflicts			
Sawyer, R., et. al.	Simulation Studies of the Super-sonic Transport in Future Air Traffic Control Systems (E-4)	S (Real time)	?	Delay, Workload, Fuel Penalty			
Sawyer, R., et. al.	Simulation Studies of the Super-sonic Transport in the Present Day Air Traffic Control System (E-5)	S (Real time)	?	Delay, Workload, Fuel Penalty			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY F: COST-EFFECTIVENESS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
ARCON Corp.	Study of Future Oceanic Aviation Support Systems (F-7)	P,D,A	?	Cost, Risk Level, Communications Load			
Attwooll, V.	The Costs of Terminal Area Delays (F-1)	D,A	—	Cost			
Attwooll, V.	The Parallel-Route System for North Atlantic Subsonic Jet Traffic (F-2)	S	Atlas	Cost, Delay			
Carlin & Park	A Model of Long Delays at Busy Airports (F-3)	D,A	(JOSS)	Cost, Delay	Airport(3)		
Crane, J.R.	Simulation of an Air Traffic Control System (F-8)	P,S	CDC 1604	Cost			
Kiefer, D.W.	A Linear Programming Approach to Airport Congestion (F-4)	D,A	?	(Optimal Pricing Policy)			
Skaggs, A., et. al.	The North Atlantic Air Traffic Control System: Economic Analysis of Proposed Changes (F-5)	D,A	—	Cost, Benefits ($)			
United Research	A Method for Determining the Economic Value of Air Traffic Control Improvements and Application to All-Weather Landing Systems (F-6)	D,A	—	Cost, Benefits($)			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY E: ATC SYSTEMS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Arad, B., et. al.	Control Load, Control Capacity and Optimal Sector Design (E-1)	D,A	—	Workload			
Barnsby, A.E.	Airspace Model Description (E-2)	P,S	?		Network(3) Enroute(3)		
Burlin, C.W.	Air Traffic Control Simulation Model Exploratory Study (E-3)	D,S	IBM 360/85	Delay, Conflicts			
Sawyer, R., et. al.	Simulation Studies of the Supersonic Transport in Future Air Traffic Control Systems (E-4)	S (Real time)	?	Delay, Workload, Fuel Penalty			
Sawyer, R., et. al.	Simulation Studies of the Supersonic Transport in the Present Day Air Traffic Control System (E-5)	S (Real time)	?	Delay, Workload, Fuel Penalty			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY F: COST-EFFECTIVENESS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
ARCON Corp.	Study of Future Oceanic Aviation Support Systems (F-7)	P,D,A	?	Cost, Risk Level, Communications Load			
Attwooll, V.	The Costs of Terminal Area Delays (F-1)	D,A	—	Cost			
Attwooll, V.	The Parallel-Route System for North Atlantic Subsonic Jet Traffic (F-2)	S	Atlas	Cost, Delay			
Carlin & Park	A Model of Long Delays at Busy Airports (F-3)	D,A	(JOSS)	Cost, Delay	Airport(3)		
Crane, J.R.	Simulation of an Air Traffic Control System (F-8)	P,S	CDC 1604	Cost			
Kiefer, D.W.	A Linear Programming Approach to Airport Congestion (F-4)	D,A	?	(Optimal Pricing Policy)			
Skaggs, A., et. al.	The North Atlantic Air Traffic Control System: Economic Analysis of Proposed Changes (F-5)	D,A	—	Cost, Benefits ($)			
United Research	A Method for Determining the Economic Value of Air Traffic Control Improvements and Application to All-Weather Landing Systems (F-6)	D,A	—	Cost, Benefits($)			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY E: ATC SYSTEMS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Arad, B., et. al.	Control Load, Control Capacity and Optimal Sector Design (E-1)	D,A	—	Workload			
Barnsby, A.E.	Airspace Model Description (E-2)	P,S	?		Network (3) Enroute (3)		
Burlin, C.W.	Air Traffic Control Simulation Model Exploratory Study (E-3)	D,S	IBM 360/85	Delay, Conflicts			
Sawyer, R., et. al.	Simulation Studies of the Supersonic Transport in Future Air Traffic Control Systems (E-4)	S (Real time)	?	Delay, Workload, Fuel Penalty			
Sawyer, R., et. al.	Simulation Studies of the Supersonic Transport in the Present Day Air Traffic Control System (E-5)	S (Real time)	?	Delay, Workload, Fuel Penalty			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY F: COST-EFFECTIVENESS MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
ARCON Corp.	Study of Future Oceanic Aviation Support Systems (F-7)	P,D,A	?	Cost, Risk Level, Communications Load			
Attwooll, V.	The Costs of Terminal Area Delays (F-1)	D,A	—	Cost			
Attwooll, V.	The Parallel-Route System for North Atlantic Subsonic Jet Traffic (F-2)	S	Atlas	Cost, Delay			
Carlin & Park	A Model of Long Delays at Busy Airports (F-3)	D,A	(JOSS)	Cost, Delay	Airport(3)		
Crane, J.R.	Simulation of an Air Traffic Control System (F-8)	P,S	CDC 1604	Cost			
Kiefer, D.W.	A Linear Programming Approach to Airport Congestion (F-4)	D,A	?	(Optimal Pricing Policy)			
Skaggs, A., et. al.	The North Atlantic Air Traffic Control System: Economic Analysis of Proposed Changes (F-5)	D,A	—	Cost, Benefits ($)			
United Research	A Method for Determining the Economic Value of Air Traffic Control Improvements and Application to All-Weather Landing Systems (F-6)	D,A	—	Cost, Benefits($)			

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY G: SAFETY-RELATED MODELS

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Burghart, J.	Navigation Accuracy and ATC Separation Standards Study (G-1)	P,A	—	Risk		Oceanic(1)	
Currier, J., et. al.	Collision Avoidance Algorithm for an Automated Air Traffic Control System (G-2)	P,A	—				
Filkens, L., and Little, J.	Study of Aircraft Separation Criteria (G-8)	P,A	—	Errors			
Flanagan, P., and Willis, K.	Frequency of Air Space Conflicts in the Mixed Terminal Environment (G-3)	P,A	—	Encounters			
Hockaday, S.	A Model to Investigate Separation of Landing Aircraft with Special Reference to Collision Risk (G-4)	P,A	IBM 1620	Risk		Airport(1)	
Holt, J., and Anderson	Analysis of Warning Times for Collision Avoidance Systems (G-5)	P,A	?	Escape Time		Terminal Area, Enroute(1)	
Justman, S., and Fisher, E.	Technique for Analysis of Control Capability in Air Traffic Control Systems (G-6)	P,D,S	IBM 7090	Workload, Communications Load			Enroute Workload(3) Communication(3)

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY G: SAFETY-RELATED MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Koetsch, J.F.	A Three Dimensional Mathematical Model of the Air Traffic Control Separation Problem (G-7)	P,A	—	Risk			
Lord, R.N.	Separation Standards and Aircraft Wander (G-9)	P,A	—	Errors, Risk			
Marks, B.L.	Air Traffic Control Separation Standards and Collision Risk (G-10)	P,A	Mercury	Encounters, Risk		Enroute, Oceanic(1)	
Moir, R., and Most, H.D.	A Summary of the Computer Sizing Portion of the Ground Based Collision Avoidance Function for the 1980-1990 Air Traffic Control System (G-11)	P,A	—				
Nagy, A.	Operational Analysis of Time-Frequency Collision Avoidance Systems (G-12)	P,S	?				
Reich, P.G.	A Theory of Safe Separation Standards for Air Traffic Control (G-13)	P,A	—	Risk		Oceanic(1)	
Reich, P.G.	Analysis of Long Range Air Traffic Systems (G-14)	P,A	—	Risk		Oceanic(1)	

TABLE 1.-SUMMARY OF EVALUATED MODELS (Con.)

CATEGORY G: SAFETY-RELATED MODELS (Con.)

Author	Title	Type	Computer	Primary Measures	Utility for Evaluation of: Traffic Flow	Safety	System Loading
Reich, P.G.	An Analysis of Planned Aircraft Proximity and Its Relation to Collision Risk with Special Reference to the North Atlantic 1965-71 (G-15)	P,S	—	Risk (Cumulative)		Oceanic(1)	
Rossman, D., and Kirchoff, R.	Ground Based Collision Avoidance Function for the 1980 Air Traffic Control System (G-16)	P,A	—	(Computer Requirements)			
Scott, P.P.	Studies of Traffic Packing for Estimating Mid-Air Collision Risks over the North Atlantic (G-17)	P,A	—	Risk		Oceanic(3)	
Steinberg, H.A.	A Safety Model for Evaluating Risk Involved in Airport Landing Operations (G-18)	P,A	—	Risk		Airport(2)	
Taylor, W., et. al.	Theoretical Minimum Separation of Parallel Runways (G-19)	P,A	—	Risk		Airport(1)	
Treweek, K.H.	An Approach to the Problem of Estimating Safe Separation Standards for Air Traffic (G-20)	P,A	—	Risk			
Wolff, W.	An Analytical Approach to a Separation Hazard Prediction and Resolution Model (G-21)	P,A	?			Terminal, Enroute(3)	

USER'S GUIDE

I. GENERAL

This guide consists of 5 major sections:

A. Model Categories: The model categories are described by subject area.

B. Model Evaluation: The format of the general evaluation is described.

C. Bibliography: Use of the master and categoric bibliographies is detailed.

D. Key Word List: Use of this list is explained.

E. Future Changes: Comments are made concerning recommended procedures for additions and/or alterations.

II. DEFINITIONS

A. Model Categories

The model descriptions and evaluations are divided into seven categories, characterized by subject area. A summary description of the types of models which are included in each group is presented below. A more detailed description of model types, results, and possible applications is provided at the beginning of each category in the Overview.

The seven model categories are:

(A) Airport surface traffic models: taxiways, aprons, and gates.

(B) Runway/Final approach models: models of runway capacity, runway utilization (departures, arrivals and combinations thereof), and queuing patterns.

(C) Terminal area models: considering traffic in and out of a terminal area; also models of holding stacks, pre-final approach spacing,etc.

(D) Enroute traffic models: airways, airway intersections, and Air-Route Traffic Control Centers.

(E) General ATC system models: models of the overall ATC system; this class also includes models that cannot be included in any other of the categories (e.g. controller workload model).

(F) Cost/effectiveness analysis models.

(G) Safety-related models: collision probability as function of traffic density, separation standards, etc.

B. Model Evaluation

The model evaluation is divided into the following sections:

(1) Model-One of the preceding seven model categories is designated, or the model is more accurately described in very brief detail. If a single report describes more than one model, reference is made to the separate models in the evaluation or separate evaluations are presented for each model. Also it is possible that a single model may completely integrate elements from more than one of the seven categories. In this case separate cross-reference entries are provided. Such a cross-reference contains only Parts (1) and (2) of an evaluation, and a statement is included in Part (1) which tells where the complete evaluation can be found.

(2) Identification of Related Report - This section contains complete bibliographic information about the related report. Included items are title, author(s) (a complete list with primary author first),originating agency, agency's report number (other I.D. systems and numbers; project sponsor), and date of completion.

(3) Summary - If the author's abstract sufficiently summarizes the report, only the abstract is included in the summary. If not, a short description of the report is entered in place of - or along with - the abstract.

(4) Model Type - This briefly categorizes the report as to its approach, i.e.

i) Quantitative vs. qualitative

ii) Probabilistic vs. deterministic

iii) Analytical vs. simulation

iv) Optimal vs. heuristic

Any additional information which clarifies the system is also included, but single word descriptors apply most frequently.

(5) Features and Assumptions - This section lists the distinguishing features and assumptions of the model in the context of the ATC area under consideration. Also noted are aspects which are not considered in the model. Model faults or deficiencies are listed, too.

(6) Major Results - The objectives of the model development, the principal outcomes, and the form of the results are described in this section. Customer use and final disposition of the model are included when appropriate.

(7) Documentation - If the related report is well-written and well-documented with definitions of parameters, discussion of assumptions and variables, details of methodology, descriptions of computer software(flow charts, inputs, outputs and program listing) and effectiveness measures, it is described as complete. Otherwise, report contents are specified.

(8) Completeness - This section describes the stage of development of the modeling effort. If it is complete, information on whether or not - and how - validation was accomplished is given.

(9) Computer Implementation - Some idea is given as to the difficulty of implementing the model in a computer program. If the model has already been prepared for a computer, the language and specific computer are named. Implementation or extension is described as simple, considerable effort, or major project.

(10) Flexibility and Modularity - An indication as to how easily the model can be extended to include additional considerations and suggestions for extensions of the model are included in this section. Frequently the author has already suggested such extensions. Also comments are made if the model could be included in a larger system of models.

(11) Evaluation - A definite indication of appraisal is given in this section and, hence, it may be the most important aspect of the entire cataloging effort. In addition to an absolute rating, comparisons to other models are made whenever possible. Specific reasons for these appraisals are listed in order to provide a guide as well as an evaluation for potential users of the models.

C. Bibliography

A listing of all reports concerning ATC models and simulations that were examined is given in the Bibliography. Complete bibliographic details are contained there. The entries are grouped alphabetically by the authors' last names (or agency if no single author is listed). Separate pages are used for each letter of the alphabet to facilitate continuation of the catalog. A report that has been formally reviewed has the catalog review number given; cross-references are also cited. The review number designates the category in which the review is found and its position within that category. For those reports that were examined, but not reviewed, there is no other comment. Additionally every entry in the bibliography has been assigned to one or more categories depending on the nature of the report. Lists of these categorical entries appear after each Overview, but they are comprised of author and title elements only.

D. Key Word List

A key word (or phrase) list has been implemented. Evaluations that pertain to specific key words are listed there by category and number.

E. Future Changes and Additions

The extensive literature search for this project involved nearly 1200 titles of interest to ATC researchers. Fewer than 200 of these described modeling or simulation efforts, and only 88 of these few were of significant scope to warrant a written evaluation. Unfortunately in spite of the large-scale search some significant works - both old and new - continue to be discovered by the investigators. Thus, the need for continuation is obvious if this catalog is to be useful in the future. The format is such that it can readily accommodate additions and changes. Such entries can be added to the appropriate alphabetic bibliography pages, the category listings can be up-dated, and the reviews can be numbered sequentially and entered at the end of the categories.

OVERVIEW

Category A - Airport Surface Traffic Models

The models considered in this section are those related to the movement of aircraft and other vehicles on the airport surface. The total traffic on the airport surface (exclusive of runway use) consists of aircraft taxiing between the runway and gates, aircraft taxiing to and from cargo areas, maintenance areas or specialized terminals; and a variety of trucks and other ground vehicles.

The models of this category are usually addressed to the determination of such things as taxiway capacity, delay statistics, total airport surface flow rate, optimal intersection crossing strategies or optimal routes, as functions of taxiway design characteristics, exit and entrance location, gate locations and service rates, operational procedures,environmental factors, traffic composition and applied demand levels.

The general purposes of developing such models are (1) to aid in the design of the surface system, (2) to aid in the evaluation of operational procedures and strategies, and (3) to provide a basis for software for automatic guidance and control systems.

In contrast to the number of models developed for the analysis of runway capacity, relatively few models have been developed which simulate the flow of traffic through the complete ground network; and only preliminary studies have been conducted dealing specifically with taxiway or ramp capacities. A possible reason for the relative scarcity of such models is that the marginal gain in total airport throughput due to changes in taxiway configuration or operation might be of the order of 5%, whereas the gains due to changing such things as number of runways, arrival spacing, etc. are of the order of 50% or more.

Computer models which simulate traffic over the total airport surface have been developed by United Aircraft Corporation (by S.Hall - reviewed in this section), R. Dixon-Speas Associates (by E. Joline - also reviewed in this section), and by the New York architectural/consulting firm of Tippet, Abbet, McCarthy and Stratton. These models are proprietary. The latter two have been utilized in the planning of specific airports. The Dixon-Speas' ASM-2 has been used to evaluate Philadelphia and Phoenix, and the TAMS model has been used for the Dallas regional airport. There appear to be no complete surface simulation models available to the government.

The documents by E. Dowe of the FAA/NAFEC and by J. Tucker and J. Huggett of the University of California (Berkeley), are preliminary studies and proposed methodologies of simulating surface traffic. Both are reviewed here, and are highly recommended for those interested in developing a simulation, or in analyzing certain aspects of surface design or operations. The proposed methodologies consider a greater number of variables (especially Dowe's study) than are apparent in the available descriptions of the proprietary computer models.

Category A
Airport Surface Traffic Models

	Review Number
Achitoff, L., "An Airport Surface Traffic Control System (STRACS)"	
AIL, "Analysis of Techniques for Aircraft Ground Guidance at Airports"	
Dowe, E.J., "A Method for Computer Simulation of Airport Surface Traffic"	A-1
Hall, S., "A Simulation of the Airside Traffic at an Airport"	A-5 C-14
Horonjeff, R., Finch, D.M., "Ground Guidance and Control in Poor Visibility"	
Horonjeff, R., et. al., "A Mathematical Model for Locating Exit Taxiways"	A-2
Joline, E., et. al., "Simulation Model ASM-2"	A-3
Tucker, J.R., Huggett, J.W., "A Preliminary Investigation into the Taxiway Congestion Problem"	A-4

1. Model: Airport Surface Traffic Simulation

2. Identification of Related Report:

   Title: A Method for Computer Simulation of Airport Surface Traffic.

   Author: Edward J. Dowe

   Agency: FAA, National Aviation Facilities Experimental Center, Atlantic City, N.J.

   Report: FAA/NAFEC Report NA-69-47

3. Summary

This report details the physical and operational characteristics of airport surface traffic which should be considered in the development of an airport simulation model. The purpose of such a simulation would be to evaluate (in terms of delays, number of conflicts, and aircraft transit time through a taxiway system) the effects of design changes or procedural changes at airports.

The simulation would consist of the following major functional parts: (1) Traffic Generation (traffic characteristics, demands, distribution patterns, runway utilization inputs), (2) Route Selection, (3) Departure Simulation, and (4) Arrival Simulation.

Abstract

A method of simulating airport surface traffic using a fast-time digital simulation technique is presented in this report. The control process that regulates airport traffic (both aircraft and ground vehicles) is described, and it is proposed that the airport surface environment be handled by taxiway and terminal subsystems. A method of approach is described for generation of the traffic samples, route selection, conducting the simulation, and validation of its results. It was concluded that digital simulation methods are feasible to produce quantitative improvements in the use of the airport surface. A bibliography of references is included.

4. Model Type

   If developed, would be probabilistic, computer simulation.

5. Features and Assumptions

   Delay is considered to be the best measurement of effectiveness.

   The physical system of interest consists of (1) the taxiway subsystem (between the runway and the apron) and, (2) the terminal subsystem (between apron edge and the gate).

The four major functional parts of the suggested computer simulation are (1) Traffic Generation, (2) Taxiway Route Selection, (3) Arrival Phase Simulation, and (4) Departure Phase Simulation. For the traffic generation, it is suggested that the simulation cover the 3 hour period which brackets the peak demand time; and that arrivals/departures be sorted into categories (aircraft mix, carrier, etc.). The arrival and departure rates for each category would be based on the Official Airlines Guide and local surveys. The actual times assigned in the simulation would be determined by random sampling from distributions constructed from surveys.

For the Route Selection function, a matrix would be constructed of all possible routes (consisting of combinations of taxiway segments and various intersections) for all combinations of take-off runways and landing runways.

In the Departure and Arrival Simualtions the most important statistics are considered to be:

(1) Total travel time (for each aircraft)
(2) Queue data at runway thresholds, gates, intersections; especially number in queue and waiting time
(3) Number of conflict situations
(4) Zero-delay, zero-conflict transit time

6. <u>Major Results</u>

The purpose of this in-house FAA study was to provide a methodology for the computer simulation of surface traffic movements at airports. The paper constitutes a first step in the development of a simulation tool suggested for FAAR 5090.1 dated August 23, 1967: "Improve Planning Tools Utilized Airport Plan"; and in FAAR 5090.2, January 10, 1968: "Provide a Means for Reducing Airport Congestion".

7. <u>Documentation</u>

There is a listing and discussion of all possible physical and operational elements and controller procedures, but there are no equations.

8. <u>Completeness</u>

This is not a simulation, but only a methodology for constructing one.

9. Computer Implementation

The author suggests a language like GPSS III. A significant effort would be required to develop and program a model.

10. Flexibility and Modularity

Because of the flow chart methods used to build descriptive models with GPSS III, modifications in logic would be able to be made without much difficulty.

11. Evaluation

This document contains a very comprehensive listing of all physical and operational characteristics of airport surface traffic and traffic control, and would be quite useful for those planning to develop an airport simulation. There are full and accurate descriptions of current airport operations and control procedures. The methodology presented is sufficient to allow analysts to construct preliminary flow charts (given the necessary data collection and analysis efforts).

1. Model: Model for Locating Exit Taxiways

2. Identification of Related Report :

   Title: A Mathematical Model for Locating Exit Taxiways

   Author: R. Horonjeff, et. al.

   Agency: Institute of Transportation and Traffic Engineering, University of California, Berkeley

   Report#: PB 171068

   Date: December 1959

3. Summary :

An analytical model is used for single runway landings. The model makes it possible to determine the taxiway locations that will yield the highest average runway acceptance rates, and corresponding wave-off rates, taking into account: (1) number of exits, (2) exit speed, (3) aircraft arrival rates at runway threshold, (4) aircraft population mix, (5) pilot variability, and (6) meteorological and geographical conditions.

The model was exercised and the results showed that the optimum locations and the corresponding acceptance rates are quite sensitive to aircraft population, exit speed, and number of exits. Furthermore, if the number of exits and intervals of time between aircraft arriving over threshold are fixed, the optimum locations of the exits vary considerably for each aircraft population.

Since the model consists of a system of non-linear partial differential equations, it was necessary to use numerical computation procedures on a computer. The differential equations were transformed into a system of transcendental equations, which were solved using successive approximation procedures.

4. Model Type :

   Quantitative; "static" probabilistic (i.e., not a Monte Carlo-type simulation). System of equations must be solved by numerical techniques.

5. Features and Assumptions :

   The model must be operated with the assumption that aircraft arrive over the runway threshold either at fixed intervals of time or at fixed intervals of distance. Another primary assumption is that there are never two consecutive wave-offs. In other words, if an accepted aircraft fails to achieve the last exit, it must go to the end of the runway but the total occupancy time will not be so great as to cause a wave-off.

Other assumptions include: (1) no accidents; (2) no wind change during arrival period; (3) the arriving population consists of known percentages of each aircraft type and that these percentages do not change during the arrival period being studied; (4) aircraft are processed on a first come - first served basis; (5) the aircraft decelerates to and maintains exit velocity until it clears the runway, and in addition an aircraft cannot exit if its speed at the turn-off point is greater than the specified exit velocity.

When the model was exercised, comparisons were made among the average acceptance rates for various combinations of conditions. The acceptance rates used were selected from that region which is (arbitrarily) bounded by wave-off probabilities of 0.5% and 1.0% so that the average acceptance rate is within 0.5 - 1.0% of the applied arrival rate. This "balance" region is of special interest to the designer because it in effect represents situations where the runway is at capacity.

6. Major Results :

This work was commissioned by the FAA/BRD Operations Analysis Directorate in order to determine the effects of exit taxiway location on runway acceptance rate. The model determined optimum exit locations for given set of conditions; these conditions were (1) number of exits, (2) exit speed, (3) aircraft population and (4) arrival separation scheme. The measure of effectiveness is the average acceptance rate.

Results are presented in tables of exit locations for various conditions. Graphs of acceptance rate are also shown.

7. Documentation :

The documentation is essentially complete, except that the program listing is not given. Assumptions are explicitly listed, and the development of the equations is presented in detail.

8. Completeness :

The basic mathematical model for landings is complete. A preliminary discussion of evaluating runway turn-ons is initiated; it is not complete.

9. Computer Implementation:

Although the program listing is not provided, it should not be difficult to implement the model. The computer used in the application was an LGP-30 with 4100 word memory and a typewriter I/O device.

10. Modularity and Flexibility :

The model is a precision tool to aid in the design and location of exits. It could fit into a higher level model developed to evaluate or optimize airport designs.

11. Evaluation :

The overall quality of the model is very good. The assumptions are explicitly stated and the equations are derived in detail. There are two uses for the model. The primary use, that for which it was developed, is to determine the optimum location of exits given a certain population mix, separation scheme, exit speed and number of exits available. In this respect the model can be a useful tool in airport planning. The model must, of course, be supplied with more modern data on aircraft population mix and aircraft deceleration characteristics. It should be kept in mind that the model can also be used to compute, for an existing airport where runways are already fixed, the average acceptance rates and percent wave-offs for various conditions. Several models which have been developed since the date of this work would appear to be more appropriate for this purpose. These models are evaluated in Category B, Runway/Final Approach Models.

1. Model : Airport Surface Traffic

2. Identification of Related Report :

Title: Simulation Model ASM-2
Author: Everett Joline, et.al.
Agency: R.Dixon Speas Associates
Report: Sales brochure (1970)

3. Summary :

The computer is used to generate aircraft movements through landing, taxiing, gate use, and departure. The rate of movement and aircraft performance all simulate real life operations.

ASM-2 is written in SIMSCRIPT II, the latest most powerful version of SIMSCRIPT. Input to the model includes data on the airspace and airport geometry in the form of node/segment connection data, flow constraints, and node location coordinates. Aircraft are classified into performance categories and with specific speeds, accelerations, and other performance data.

Subprograms are used to describe routing, runway selection, aircraft sequencing, and other functions normally performed by human controllers; so that changes can be made in these procedures so as to reflect local practices without recompilation of the whole program. The rules as presently implemented represent general practice as observed by the Speas' staff at representative airports.

Input traffic to the model can be produced by statistical generation or by preparation of a specific schedule tape. The statistical generation program can vary the volume of traffic, the ratio of arrivals to departures, and the aircraft type mix to determine sensitivity of system performance to these factors. When performance estimates are required in terms of absolute values, a more specific schedule can be prepared using a program developed for this purpose by Planning Research Corporation. This program develops a timetable for future years based on current traffic patterns, modified by anticipated aircraft technology changes and volume growth factors.

A variety of output can be obtained from the simulation. A listing of the sequence of events in airport operations can be obtained to check the operation of the model against the real world. In addition, for each set of input parameters, statistical compilations provide summaries of delays, utilization of facilities, and the accuracy of system performance.

A special feature of the ASM-2 computer program is provision for an interface with a program for preparation of computer drawn motion pictures. These motion pictures will demonstrate the comparative advantages of the different control and facility concepts in a graphic form.

4. Model Type : Quantitative; probabilistic; simulation

5. Features and Assumptions :

(1) Aircraft arrive in terminal area randomly distributed about scheduled arrival times. They are assigned a runway, queued for landing at the feeder fixes, and cleared for approach at intervals that maintain required approach spacings for the particular aircraft speed class and the particular approach geometry.

(2) Aircraft arrive at runway threshold with random variations of speed and spacing that reflect actual pilot and controller performance.

(3) A runway exit is selected as a function of the speed rating of the exit and the aircraft approach speed and deceleration capability.

(4) After leaving runway each aircraft is assigned a gate of the appropriate type or routed to a hold area if the airline has no gate available. Aircraft will follow shortest route consistent with any taxiway usage constraints that have been imposed.

(5) Taxi speeds are reduced as aircraft enters gate area and follows parking procedure.

(6) Time spent at gate is a function of schedule time, actual arrival time, type of flight continuation, and aircraft type.

(7) Take-off aircraft will allow appropriate separation interval after previous departure as a function of aircraft type, departure route geometry and observed controller performance. Departures will hold if necessary for landings on a close parallel or crossing runway and for in-progress runway crossings to be completed.

(8) Aircraft will hold at runways for take-offs and cross after the take-off aircraft has cleared the intersection.

(9) Aircraft will hold at intersections for interfering traffic or if next segment is blocked by traffic. Successive aircraft will queue up at end of a taxiway segment and move up as preceding aircraft leave the segment.

(10) Departing aircraft follow departure routes as determined by destination zones and route restrictions in effect.

6. Major Results :

ASM-2 is an improved and expanded version of ASM-1 which has been applied to the airports and airspace in New York, Puget Sound and Toronto. ASM-2 has been used to evaluate Philadelphia and Phoenix. The simulation can be played back on a computer generated movie which shows all the aircraft moving relative to the airport map as a background in real or fast time. This is in addition to the usual statistical analysis and output.

7. Documentation : information available only through R.Dixon Speas Associates plus sales brochures - possible to lease the program.

8. Completeness : ASM-2 is actually the third version of airport simulation starting from 1965. Latest version completed in May 1970.

9. Computer Implementation : SIMSCRIPT II

3 hours of traffic takes 9 sec. on IBM 360-85.

Only compiled once-subroutines can be changed separately.

10. Modularity and Flexibility :

The simulation can be tailored to a specific airport by programming appropriate coordinates of intersections, turnoffs, etc. It could also be adapted to a larger simulation, but this would require involvement of R. Dixon Speas Associates.

11. Evaluation :

The model provides a realistic and detailed simulation of airport traffic. The movie output is quite impressive. Besides serving as a sales demonstration it also allows the practical expert to check on details of the analyst's logic and the realism of the simulation. The major utilization of the simulation is for the detailed planning of specific airports. It is particularly useful for predicting the effect of new taxiways, gate availability runway changes, ground routing, etc.

1. Model : Airport surface

2. Identification of Related Report :

Title:	A Preliminary Investigation into the Taxiway Congestion Problem.
Author:	J. R. Tucker and J. W. Huggett
Agency:	Institute of Transportation and Traffic Engineering, University of California
Report #:	(none)
Date:	September, 1968
Other I.D.:	Graduate Report

3. Summary :

The authors propose the development of a simulation model to be used to examine problems of airport surface traffic. The primary uses they suggest are to examine surface delay as a function of taxi network configuration, taxiing strategy, aircraft population mix, and demand level. The airport surface is divided into four physical elements: the runway element, the taxiway element, the intersection element and the apron element. The model is not developed, but there is a general flow chart for each of these elements which could be increased in detail.

Fixed and variable inputs are listed for the different elements along with suggested output statistics. Typical outputs would be queue statistics at intersection and gates, runway occupancy, element utilization, exit details, etc. There are some simple and useful graphs showing time requirements for various intersection crossing strategies and shows the relations between taxiway velocities and segment lengths. There is quite a bit of surface movement data, taken from observations at SFO.

4. Model Type :

Proposal of a quantitative computer simulation.

5. Features and Assumptions :

Runway occupancy is considered as the starting and finishing point for taxiing maneuvers on the airport surface.

Ambient conditions, air traffic control strategy and navigation aids, and certain aircraft characteristics would be considered as fixed inputs for each simulation; as well as the number of taxiway segments.

Model parameters such as taxiing velocity (as a function of taxiway length or taxiing radius), runway occupancy time and intersection crossing time would presumably be described by frequency distributions.

6. Major Results:

Many of the authors' observations on factors which affect taxiway flow are incorporated in Appendix B-7, "Airport Design Considerations", of the 1969 Air Traffic Control Advisory Committee report.

Among these observations are:

(1) The taxiway flow rate increases linearly with taxiing velocity up until $\sim$ 20 mph, after which it increases at a decreasing rate until it reaches a maximum. The flow rate then decreases with increasing vehicle velocity, due to the greater spacing which the aircraft maintain.

(2) The platoon method of crossing intersections results in a smaller average delay to each aircraft since some of the acceleration and deceleration times are eliminated.

(3) Times for crossing runways may range from 14 to 26 seconds (based on observations at San Francisco International).

(4) Platoon movements must be employed with bi-directional taxiways; however, the amount of time that the bi-directional taxiway is not maximally utilized is a direct function of the length of the particular taxiway section. Thus, a taxiway should be used for one direction only if high movement rates are required.

(5) A high speed runway exit designed for 60 mph, will normally be used with a velocity dispersion of 20 to 40 mph.

7. Documentation:

No detailed flow charts, equations or program listings.

8. Completeness:

This is only a preliminary investigation and a proposal to develop a simulation model.

9. Computer Implementation Requirements:

A major effort would be required to develop and program the model.

10. Flexibility and Modularity:

The proposed modular construction appears to allow a great deal of flexibility at this early stage.

11. Evaluation:

This is not a model but essentially a proposal to develop one. Consequently, it would be of limited utility to an airport design analyst as it presently exists. There are some good graphical presentations of distance - time relationships for various intersection crossing strategies. There is a good deal of quantitative data, taken at San Francisco International, on intersection crossing times (runway and taxiway crossings), runway landing occupancy times, runway exit speeds, and taxiing speeds for varying taxiway lengths.

The document by E. Dowe, reviewed elsewhere in this section, contains a more comprehensive listing and discussion of possible simulation inputs and parameters; however, this document is still an excellent beginning for analysts who are interested in developing an airport surface simulation model.

1. Model : Final-Approach and Runway-Landing Capacity/Airport Surface

2. Identification of Related Report :

   Title: A Simulation of the Airside Traffic at an Airport

   Author: Stephen Hall

   Agency: United Aircraft Research Laboratories

   Report: J-170648-1

   Date: July 28, 1970

3. Summary :

As part of a continuing study in the problems confronting future development and expansion of air transport operations, the United Aircraft Research Laboratories has developed a computerized airport model comprising a Monte Carlo simulation of the flow of airside traffic. In this model the entire airport airside system, including its airborne traffic, is treated as a stochastic process which is analyzed by the repetitive-trial technique.

Each of several time intervals within the system is expressed as the sum of a constant and a random variable. The values for the constants and the averages of the random variables are selected by the operator who thereby controls not only the mean length of each time interval but also the extent of its randomness. Mean arrival rates and ground dwell times for aircraft are inputs in the form of diurnal cycles having hourly variations. The inputs can be selected to describe each individual airport under consideration. Thus, variations in runway configurations, approach terrain, weather, traffic samples, etc., can be tailored to the specific airport being studied, rather than being derived from average statistics which may not represent the true local situation.

Complete descriptive details of this program are discussed, including components of the system, the simulation of air traffic flow, and the computational flow of the simulation. In addition, an illustrative example is shown of a busy two-runway airport operating under Instrument Flight Rules. Results of this example

show the expected hourly variations in system saturation and congestion, and estimates of the median and 90 percentile delays for each hour of the day for arrivals, gate occupants, and departures.

This study was performed as part of the Research Laboratories' Corporate sponsored systems analysis program.

4. Model Type : Quantitative; Probabilistic; Simulation.

5. Features and Assumptions:

Queues may form in the holding stack, waiting for departure, or waiting for loading gates. Although not described in the paper the simulation has been run without including the loading gates.

6. Major Results : Trial simulation of JFK on a typical summer day.

7. Documentation : Flow chart in report; program available through author.

8. Completeness :

This report describes only a demonstration effort to prove the capability of the simulation. The author intends to apply the model to a larger simulation.

9. Computer Implementation : FORTRAN V

24 hours of traffic in 2 sec.
100 trial runs in 3 min 4 sec.
UNIVAC 1108.
Modular capability - simple effort to adapt.

10. Modularity and Flexibility :

The model can be adapted to any particular airport. It is particularly well-suited for V/STOL ports. It could also be adapted to intersecting runways with modification.

11. Evalution :

The model provides a realistic simulation if the user has a good estimate of the statistical parameters. The model requires input data on actual departure and arrival frequencies which may be difficult to obtain. The model is particularly useful for looking at the throughput of a single airport, and it could be of great value as an element of a larger simulation.

OVERVIEW

Category B - Runway

This section reviews models related to the runway and final approach.

The most usual method of approach in this area is to picture the final approach/runway sequence as a service system (two-servers in series) operating at a certain service rate.

The main effort in the area has been directed towards the construction of probabilistic models for determining the airport capacity. Among these models, of primary importance are those that also consider the glide path, because, with present ATC regulations and aircraft characteristics, this server offers stronger capacity limitations than the runway. Consequently, an improvement of the glide path performance would be translated into a direct increase of the capacity. Excellent models of the glide path are due to A. Blumstein, R. Harris, A. Odoni and A. Goldman, who present similar approaches to the problem. These models determine the <u>IFR landing</u> capacity of the system. In fact, they all assume that the runway is used for landings only. A model due to R. Simpson describes the landing procedure when VFR conditions hold, and determines the <u>VFR landing</u> capacity of the system.

All the models mentioned above for the IFR case have been extended to the more general case of considering mixed operations (landings and departures) taking place on a single runway.

A slightly different approach for determining the airport capacity is due to G. Baran. He concentrates on the runway itself and determines the runway capacity for landings only, departures only and mixed operations. His models assume an ideal glide path which does not affect the capacity of the system.

A model for determining the minimum separation of parallel runways, and a second one for determining the procedure for conducting instrument approaches to parallel runways spaced less than 5000 feet apart are the only models for multiple runway configurations that are described.

The simulation models seem to have applications in the determination of congestion related statistics (queue length, expected delays, runway utilization) that-because of their complexity-cannot be modeled by a simple probabilistic analytical model.

It should also be mentioned that the definition of capacity adopted by the FAA is not the one used by most researchers in the area. While the FAA definition considers capacity as the number of aircraft that can be served with an average delay of 4 minutes, the researchers prefer to define capacity as a maximum throughput rate under saturation conditions.

Category B

Runway-Final Approach Models	Review Number
Baran, G., "Airport Capacity Analysis"	B-1
Baran, G., Bateman, R.E., Benezra, J.N., Blumenthal, R.W., "Approach Airspace and Runway Capacity Parametric Sensitivity Analysis"	B-2
Baran, G., Benezra, J.N., Blumenthal, R.W., "Runway Capacity Augmentation Study"	B-3
Blumstein, A., "An Analytical Investigation of Airport Capacity"	B-4 B-5
Faison, W.E., "An Analysis of a Procedure for Conducting Instrument Approaches to Parallel Runways Spaced Less than 5,000 Feet Apart"	B-6 G-22
Harris, R.M., "Models for Runway Capacity Analysis"	B-7 B-8
Holland, F.C., et. al., "Investigation of Computer-Aided Control Concepts in the Terminal Area"	B-9
Hooten, E.N., Galliher, H.P., Warskow, M.A., Grossman, K.G., "Operational Evaluation of Airport Runway Design and Capacity (A Study of Methods and Techniques)"	B-10

	Review Number
Koetsch , J.F., "Combined Landing and Take-off Capacity of a Single Runway"	B-13
Mallen, G.L., "A Digital Simulation of Airport Runway Utilization Comparing the Effects of Alternative Queue"	B-14
Marks, B.L., "Digital Simulation of Runway Utilization"	B-15
Meisner, M.B., "Analysis of Alternatives for Increasing Runway Capacity and Reducing Terminal Area Delays"	B-16
MITRE Corp., "Traffic Generator and Basic Approach and Landing Simulation"	B-17
National Bureau of Standards,(Goldman, A.J.), "Analysis of a Capacity Concept for Runway and Final Approach Path Airspace"	B-11
Odoni, A.R., "An Analytical Investigation of Air Traffic in the Vicinity of Terminal Areas"	B-18 B-19
Oliver, R.M., "Delays to Aircraft Serviced by the Glide-Path"	B-20
Oliver, R.M., "Delays in Terminal Air Traffic Control"	B-27
Ottoson, H.I., "A Theoretical Determination of the Probability of a Missed Approach along the Common Path"	B-21 G-23
Ottoson, H.I., "Sensitivity of a Terminal Area Control Concept to Uncertainties in Control Information"	B-22
Pardee, R.S., "Analysis of Sequencing Methods"	B-12

	Review Number
Raisbeck, G., Koopman, B.O., et al., "A Study of Air Traffic Control System Capacity"	B-23
Ratcliffe, S., "Aircraft Sequencing, Parallel Landings and the TMA Route Structure"	B-24
Simpson, R.W., "An Analytical Investigation of Air Traffic Operations in the Terminal Area"	B-25 C-1 C-8 C-9
Taylor, W., Yost, F.K., Ball, P.S., "Theoretical Minimum Separation of Parallel Runways"	B-26 G-19

1. Model : Runway/Final - Approach

2. Identification of Related Report:

Title:	Airport Capacity Analysis
Author:	Gregory Baran
Agency:	Commercial Airplane Division, The Boeing Company
Report#:	D6-23415
Date:	September, 1968

3. Summary :

ABSTRACT

This report outlines a graphical method of analysis of airfield operational capability. Aircraft acceptance and release rates for single and parallel runway systems are investigated as a function of runway configuration (including exit location), aircraft characteristics and air traffic control procedures. The approach in this analysis is to investigate parametrically the individual subsystems, subsystem relationships and successively more encompassing system models. Visibility of fundamental system relationships is preserved by this method and system performance sensitivity to specific modifications can be directly evaluated.

The analyses suggest modifications to runway, ATC, and aircraft performance which promise to increase airfield capacity. These modifications will have to be translated into possible implementations for specific airfield situations, and the implementation costs determined. A comparision of implementation costs with excessive operational costs resulting from insufficient system capacity will then provide a measure of the cost-effectiveness of any given modifications.

4. Model Type : Quantitative, probabilistic, analytical.

5. Features and Assumptions :

Maximum hourly capacity for a single runway with arrivals or mixed operations are determined both with and without FAA separation standards. Landing capacity is defined as $60/T_A$ where T_A is the mean interarrival time in minutes. The mean interarrival time is a function of approach speed separation rules and the frequency distribution of approaching aircraft pairs with unlike approach speeds. Analysis employs nomographs as a graphical method of obtaining results.

6. Major Results :

ATC separation rules are shown to be the major capacity constraint in single mode runway utilization. Substantial increases in single and parallel runway capacity are possible, but this requires increased control automation.

7. Documentation : Complete

8. Completeness : This report is a first step towards describing and overall view of ATC systems.

9. Computer Implementation : Simple

10. Flexibility and Modularity : The model is easily adapted to one with a wider scope.

11. Evaluation :

This is an excellent report on runway capacity. Although the use of nomographs is confusing at first, a good feeling for the effects of separation rules on capacity is readily obtained. No mention of safety is made in the analysis. This report should definitely be read for a good analysis of airport capacity.

1. Model : Runway/Final-Approach Model

2. Identification of Related Report:

Title: Approach Airspace & Runway Capacity Parametric Sensitivity Analysis

Author: G.Baran et.al.

Agency: Boeing Commercial Airplane Group

Report #: D6-24282

Date: January, 1970

3. Summary :

Abstract

This analysis identifies possible improvements to increase runway capacity by altering the Air Traffic Control (ATC) System in relation to the system physical parameters. Each parameter has a nominal or current accepted value as well as a dispersion or variation around this value. As these nominal values and their dispersions are adjusted to account for system improvements, capacity gains are noted and discussed. Runway, design is also discussed, including the use of high-speed exits for arrivals and acceleration ramps for departures. Methods of improving the ground complex and of increasing control precision in the approach space corridor are outlined.

The analysis summarizes three documents previously produced by the Commercial Airplane Group of the Boeing Company,Renton, Washington

1) Airport Capacity Analysis (D6-23415) by G.Baran, Sept.,1968.
2) Runway Capacity Augmentation Study (D6-23797) by G.Baran, J.N. Benezser, R.W. Blumenthal, January 1969. (Preliminary)
3) Airspace/Airport Capacity Increase Potential (Unnumbered) by G.Baran, January, 1969 (Preliminary).

4. Model Type : Quantitative, Probabilisitc, Analytical

5. Features and Assumptions :

Relevant performance quantities are assumed to be normally distributed. High-speed exits , acceleration ramps, constant approach speed, and the distance from threshold to exit are considered. The only safety factor considered is that no two aircraft may occupy the same runway at the same time. Capacity for arrivals is defined as $\frac{V_{32}}{S}(1-P_W)$

where V_{32} is the mean final approach speed, S the nominal separation, and P_W the probability of waving off the next arrival. Departure capacity is similarly defined. Mixed operations consider alternate take-offs and landings only.

6. Major Results :

"This report demonstrates quantitatively that a significant potential for approach airspace and runway capacity exists and that a functional cause-effect relationship affecting capacity can be established". The report also includes a first-order study of various possible ATC systems.

7. Documentation : Incomplete. This paper summarizes three reports.

8. Completeness : Further research is definitely recommended.

9. Computer Implementation : Simple

10. Flexibility and Modularity : The approach used is easily adapted to various systems.

11. Evaluation :

This report summarizes three reports by the Boeing Commercial Airplane Group and offers an excellent view to the future improvements in the ATC field. The suggested areas of improvement include greater runway utilization and overall system performance. Safety factors are, in general, not considered and the capacity computations appear to be a bit high. This report should be read, however, because of the excellent overall outlook of the future work in the ATC field.

1. Model : Runway/Final-Approach Model
2. Identification of Related Report:

   Title: Runway Capacity Augmentation Study (Preliminary)
   Author: G. Baran, Benezra, J.N., Blumenthal, R.W.
   Agency: Boeing Commercial Airplane Group
   Report #: D6-23797
   Date: January 1969

3. Summary :

Parametric studies for runway capacity of arrivals only, alternating arrivals and departures, and close parallel runways are conducted, indicating which parameter changes yield the highest increase in runway operations. Among the parameters are separation distance, high-speed exits for arrivals, and acceleration ramps for departures.

Abstract

An analytical study of parameters affecting runway utilization and therefore, capacity is summarized in this document. Preliminary results are shown and tentative system design criteria are established.

4. Model Type : Quantitative, Probabilistic, Analytical
5. Features and Assumptions:

Relevant performance quantities are assumed to be normally distributed. These quantities include; approach speed, touchdown speed, exit speed, distance from runway threshold to touchdown and distance from runway threshold to exit ramp. Different dispersions about these means are considered. The only safety factor considered is that no two aircraft may occupy the same runway at the same time. Capacity for arrivals is defined as

$$\frac{V_{32}}{S}\ (1-P_W)$$ where V_{32} is the mean final approach

speed, S the nominal separation and, P_W the probability of waving off the next arrival. Departure capacity is similarly defined. Mixed operations consider only alternate take-offs and landings. Acceleration ramps and high-speed exits are also considered.

6. Major Results :

A good feeling of which parameters affect capacity most is obtained. "The most dramatic increase in capacity is obtained by reducing the dispersion of the longitudinal separation from 0.5 to 0.1 nm". The report believes that a 300% increase in capacity is possible. The areas of further work are suggested to be reduction of runway occupancy time and reduction of random dispersions of time over threshold by ATC streamlining.

7. Documentation : Complete

8. Completeness :

"System design and implementation studies are necessary to ascertain the degree to which this payoff [300% capacity increase] can be capitalized on relative to implementation time scales, implementation costs and projected availability of R&D funding and procurement".

9. Computer Implementation :

There is no simulation as yet to test the capacity increases. This simulation appears to be difficult.

10. Flexibility and Modularity : Easily adapted to changes in parameters.

11. Evaluation : The model is a fairly simple and highly informative view of parameters affecting runway capacity. The dramatic increase in capacities does not appear very practical because safety measures have not been considered, but the model does show how, in the future, increased system control will greatly increase capacity. The report should be read as an indication as to where future research should be directed.

1. Model: Landing Capacity; Single Runway

2. Identification of Related Report:

   Title: An Analytical Investigation of Airport Capacity

   Author: A. Blumstein

   Agency: Cornell University

   Report#: Ph.D. Thesis

   Date: 1960

3. Summary:

This review is concerned with a model of runway landing capacity. The part of the report that describes a model of runway used for landings and take-offs is reviewed in a separate write-up. (B-5)

Excerpt from Introduction

The problem of landings on a single runway is studied. This problem has practical importance of itself, since many runways often are used for landings only, but also serves as a larger problem of a runway used for mixed operations. A model is formulated permitting determination of the landing capacity of a runway at any airport as well as the distribution of the landing-time intervals. Possible extensions of the model are indicated. The model is used to examine the parametric effects on landing capacity, and to estimate the capacity of some typical airports. Various means of improving landing capacity are considered, and reduction of space separation along the landing path is shown to be most fruitful.

4. Model Type: Quantitative, Probabilistic, Analytical.

5. Features and Assumptions:

The following assumptions are made in the analysis: i) Aircraft arrive at the gate independently and in random sequence; ii) Aircraft landing in the order in which they arrive at the entry gate; iii) Aircraft must maintain a minimum distance separation (s_o) at the gate a minimum time separation (t_o) at the runway; iv) Aircraft maintain constant velocity from the time they enter the gate until they reach the end of the runway;

and v) Aircraft are available to be landed as close to each other as separation standards permit.

6. Major Results:

Are the derivation of the expressions to determine the landing capacity, and the parametric sensitivity analysis obtained by varying the principal parameters affecting the capacity.

7. Documentation: Excellent

8. Completeness: A final report

9. Computer Implementation: Simple

10. Modularity and Flexibility:

This model could easily be extended to include additional considerations, and it could be included in a larger system of the whole landing system.

11. Evaluation:

This is an excellent model that should be studied by all researchers in the area. The report includes an excellent description of the problems that arise in determine the landing capacity, an in most cases, it formulates a solution for them. Also, it includes many results that should be considered in building new models.

In general, the report is one of the most complete documents of Air Traffic Control problems in the Terminal Area.

1. Model: Operations Capacity; Single Runway

2. Identification of Related Reports:
   Title: An Analytical Investigation of Airport Capacity
   Author: A. Blumstein
   Agency: Cornell University
   Report#: Ph.D. Thesis
   Date: 1960

3. Summary:

This review is concerned with a model for determining the operations capacity of a runway used for landings and take-offs. The part of the report that describes a model of runway used for landings only is reviewed in a separate write-up. (B-4)

Excerpt from Introduction

An analytical model is developed that relates runway operations capacity to the eight principal parameters affecting it. Extensions to this model are formulated, indicating how the basic model may be applied to situations excluded by the assumptions. Operations capacity is shown to be affected by a complex interaction of the system parameters, and it can often be increased by steps that tend to decrease landing capacity.

4. Model Type: Quantitative, Probabilistic, Analytical

5. Features and Assumptions:

The following assumptions are made in the analysis: i) Landing aircraft arrive at the gate independently and in random sequence; ii) Aircraft land in the order in which they arrive at the entry gate; iii) Landing aircraft must maintain a minimum distance separation (s_o) at the gate and a minimum time separation (t_c) at the runway; iv) Landing aircraft maintain a constant velocity from the time they enter the gate until they reach the approach end of the runway; v) Successive departing aircraft must maintain a minimum time separation (t_{od}), vi) A departing aircraft can take-off (if so ordered) as soon as a preceding landing aircraft has cleared the runway; and

vii) Aircraft are available for either landing or take-off as frequently as separation standards permit.

6. Major Results:

Are the derivation of a set of expressions to determine the capacity under different policies, and the parametric sensitivity analysis obtained by varying the principal parameters affecting the capacity.

7. Documentation: Excellent

8. Completeness: A final report.

9. Computer Implementation: Simple

10. Modularity and Flexibility:

This model could easily be extended to include additional considerations, and it could be included in a larger system of the whole landing system.

11. Evaluation:

This is an excellent model that should be studied by all researchers in the area. The report includes an excellent description of the problems that arise in determining the landing capacity, and in many cases, it formulates a solution for them.

In general, the report is one of the most complete documents of Air Traffic Control problems in the terminal area.

1. Model: Landing Separation; Parallel Runways

2. Identification of Related Report:

   Title: An Analysis of a Procedure for Conducting Instrument Approaches to Parallel Runways Spaced Less than 5000 Feet Apart.

   Author: Walter E.Faison

   Agency: FAA Systems Analysis Division

   Report#: RD-66-35
   Program Area 157

   Date: May 1966

3. Summary:

This review is concerned with a model for determining the longitudinal separation minima between aircraft landing in adjacent parallel runways spaced less than 5000 feet apart under IFR conditions. The model relates collision risk, flight path error, nominal separation and size of aircraft. It estimates the longitudinal separation minima provided the collision risk remains smaller than a desired value. This upper bound of admissible collision risk corresponds to the case of adjacent parallel runways spaced 5000 feet apart and with zero longitudinal separation minima. Also, some extreme deviation cases, such as an aircraft crossing the path of an aircraft on approach to an adjacent runway, are examined.

4. Model Type: Quantitative, Probabilistic, Analytical.

5. Features and Assumptions:

   The model assumes that the flight path errors of an aircraft in the three dimensions are independent, the flight path errors of two (a pair) aircraft in proximity are independent, and the observations of flight path error are independent. A model deficiency is the assumption that aircraft enter the turn-on area with the correct longitudinal separation. The controller/pilot performance is considered implicitly in the flight path errors.

6. Major Results:

The objective of this model is to derive expressions to determine the longitudinal separation minima as a function of runway spacing. The results are given in tables, and it was found that the model was generally insensitive to large changes in the input values, except for the effect of the standard deviation of longitudinal flight path error.

7. Documentation:

The report includes the definition of all variables considered, but the equations are not derived because this model has been developed in other reports (see Evaluation).

8. Completeness: A final report.

9. Computer Implementation: No information is given.

10. Modularity and Flexibility:

Further study of the resolution of extreme deviation incidents which include measures of the performance of the controller, pilot and associated equipments is recommended by the author. There seem to be little possibilities for including this model in a large system.

11. Evaluation:

This is a good model that because of its high dependence on other reports should be studied with these, 1)" Evaluation of Parallel Runway Spacing", J.A. Fantoni; 2)"Air Traffic Control Separation Standards and Collision Risk", B.L. Marks; 3)"A Theory of Safe Separation Standards for Air Traffic Control", P.G. Reich, and 4)"An Analysis of Planned Aircraft Proximity and its Relation to Collision Risk", P.G. Reich. A great deal of the data used by this model was obtained from the first report mentioned above, and the model was developed in the other three reports.

The report does not say how the actual computation took place, but good tables show some results (longitudinal separation minima) with their respective input values.

Although this report deals with the application of the model rather than with the construction of the model, because of the results obtained, it could be used for further research in the area.

1. Model : Landing Capacity, Single Runway

2. Identification of Related Report :

   Title: Models for Runway Capacity Analysis

   Author: Richard M. Harris

   Agency: MITRE Corporation

   Report #: 4102

   Date: 30 October 1969

   Other I.D.: Contract DOT-FA69NS-162

3. Summary :

   This review is concerned only with the model of a runway used exclusively for landings. The part of the report that describes a runway used for mixed operations is reviewed in B-8.

Abstract

This report examines a family of mathematical and simulation models for the calculation of single runway IFR capacity. With the basic statistical model one can calculate basic saturation capacity under arrival only and mixed arrival/departure operations. In addition extensions have been made into the analysis of less-than-saturation demand by a simple queuing model, and of speed-class sequencing as a Markov process. A statistical model was used to predict capacities for alternative runway configurations, levels of approach control system precision, and changes in aircraft separation standards. This analysis was performed in support of the Department of Transportation Air Traffic Control Advisory Committee and was used to compare both single and parallel runways.

4. Model Type : Quantitative; probabilistic; analytic (there is also reference to a simulation related to the compilation of queuing statistics).

5. Features and Assumptions :

The model assumes a first-come, first-serve, discipline for arrivals, use of the runway by aircraft with varying approach speeds, and adherence to separation standards with small probability of violations. Several types of spacing errors (at the runway threshold, at the gate of the glide path) are assumed and expressions for runway capacity are obtained under such conditions. The distribution for approach speeds of aircraft is assumed to be discrete. Queuing statistics are estimated by using formulae for M/G/1 queues.

6. Major Results :

General formulae for estimating runway capacities and related delays given approach control system precision, separation standards, and mix of aircraft using the runway. Sequencing of arrivals according to speed class is shown to result in little improvement on the capacity of the runway.

7. Documentation : The analytical results are completely documented. However the simulation program is only briefly mentioned and is nowhere described.

8. Completeness : A final report.

9. Computer Implementation : It is rather simple to write a computer program that implements the described model. Such a program has already been written (in GPSS for a 360 computer), apparently, by the author but it is not described in the report.

10. Modularity and Flexibility : The model presented can easily be included in more general systems.

11. Evaluation :

The analytical model presented in this report should be included in the list of the good available capacity models of a single runway used for arrivals only (B-2, 3, 4, 9). The expression for estimating expected inter-arrival times (and, hence, capacity) under saturation conditions is simple and easy to use. The distribution of "errors" (on which capacity depends critically) reflects the degree of accuracy in spacing and scheduling aircraft that different control regimes can achieve. On the negative side it is possible to criticize the assumption of discrete approach speeds for incoming aircraft.

This report should be studied and can provide the basis for future work in this area.

1. Model : Operations Capacity - Single, Dual Lane Runways

2. Identification of Related Report:

   Title: Models for Runway Capacity Analysis

   Author: Richard M. Harris

   Agency: MITRE Corporation

   Report#: 4102

   Date: 30 October 1969

   Other I.D.: Contract DOT-FA69NS-162

3. Summary:

   This review is concerned only with that part of this report which describes a model of a runway used for mixed operations (Chapters 3 and 6).

Abstract

This report examines a family of mathematical and simulation models for the calculation of single runway IFR capacity. With the basic statistical model one can calculate basic saturation capacity nder arrival only and mixed arrival/departure operations. In additon, extensions have been made into the analysis of less-than-saturation demand by a simple queuing model, and of speed-class sequencing as a Markov process. A statistical model was used to predict capacities for alternative runway configurations, levels of approach control system precision, and changes in air-craft separation standards. This analysis was performed in support of the Department of Transporation Air Traffic Control Advisory Committee and was used to compare alternative ways of increasing the IFR capacity of both single and parallel runways.

4. Model Type : Quantitative; probabilistic; analytic.

5. Features and Assumptions :

Two situations are modelled: (a) Departures are inserted between arrivals, only when the interarrival gap is long enough to permit such an operation. (b) Arrivals are intentionally spaced far enough to always allow a departure to be inserted between two successive landings. The analysis is performed for a variety of minimum departure/arrival and arrival/arrival separation requirements. The mixed operations rate is also estimated for "dual-lane" runways, with one lane used for arrivals and the other for departures.

6. Major Results :

Mixed operations capacity of a runway under a variety of minimum depature/arrival and arrival/arrival separation requirements. Dual-lane runways are shown to be the most promising alternative in terms of increasing capacity.

7. Documentation : Complete.

8. Completeness : A final report.

9. Computer Implementation : Simple.

10. Modularity and Flexibility : The model presented can easily be included in more general systems.

11. Evaluation :

This model can provide good "first order" estimates of the mixed operations capacity of a runway. It gives a clear indication of the trade-offs involved between, on the one hand, according complete priority to arrivals over departures, and, on the other, increasing mixed operations capacity of a runway. However, some of the alternatives suggested as viable, particularly those involving 40 second departure/arrival separations do not seem realistic (in terms of safety) under present or near future, guidance and control conditions. Therefore some estimates of possible increases in operations capacity seem over-optimistic. However, the report makes a clear case in favor of dual-lane runways. These runways also minimize the safety problems.

1. Model: Landing Capacity; Single Runway

2. Identification of Related Report:

Title: Investigation of Computer-Aided Control Concepts in the Terminal Area

Author: Holland, F.C. et.al.

Agency: FAA Systems Research and Development Service

Report#: RD-64-83

Project #: 101-200R

Date: June 1964

3. Summary:

In the first part of this report the formula for determining the average landing rate is derived, and in the second part computational results are shown in charts and tables for different system parameters.

Abstract

A method for determining theoretical average landing rate has been derived. There has also been an extension of the landing rate as a function of speed and gate errors have been determined for safety separations of 2 n.mi. and 3 n.mi., for a given mix of aircraft types, and plotted on contour charts. These charts allow rapid computation of landing rate for a given standard deviation of gate and speed error and should be useful in estimating the increases in landing rate that can be obtained by reducing gate and speed errors. The study has also shown that the effect of a short inner gate for low performance aircraft is to raise the landing rate about 10% for performance mixes which might be expected at a large airport.

4. Model Type: Quantitative, Probabilistic, Analytical.

5. Features and Assumptions:

It is assumed that there is an infinite sequence of aircraft waiting to land which are classified according to speed. An average speed for each class, and a unique speed standard deviation are also assumed.

6. Major Results:

The major results are the derivation of the expression for the average landing rate, time numerical results obtained for it and for the required buffer time for different system parameters. Also, charts of the landing rate as a function of the effective ILS wind velocity, and as a function of the distance of the inner gate from the runway for two mixes of aircraft are given.

7. Documentation: It is well documented.

8. Completeness: A final report.

9. Computer Implementation:

An IBM 7090 computer program was written to determine the average landing rate for a mix of 6 different aircraft speed classes. No mention is made of the language used. The minimum amount of buffer time required between an aircraft pair is found by computing the probability of a missed approach with zero buffer time and constantly adding more and more time until the probability is less than the desired amount.

10. Modularity and Flexibility:

An extension of this model mentioned in the report is to compute buffer times for a large range of possible mean aircraft ground speeds.

11. Evaluation:

The principal characteristic of this model is the classification of landing aircraft according to their ground speed. This classification simplifies the model to a great extent making the computation easier, and many arguments can be brought up on whether it is realistic or not, but it must be mentioned that the results obtained for the landing rate (capacity) are compatible with those obtained by more sophisticated models based on a different set of assumptions. The idea of considering a buffer time is good and worthy to be considered for more developed models.

1. Model: Runway Operations Capacity

2. Identification of Related Report:

   Title: Operational Evaluation of Airport Runway Design and Capacity (A Study of Methods and Techniques).

   Author: E.N. Hooten, H.P. Galliher, M.A. Warskow, and K.G. Grossman.

   Agency: Airborne Instruments Laboratory

   Report#: 7601-6
   Date: January, 1963
   Other I.D.: AD# 417 202

3. Summary:

Abstract

Described is a continuation of research into the application of mathematical techniques to the evaluation of practical airport capacity and delays. Since the primary task was to develop a handbook for determining airport capacity and delays by the engineer in the field, the main effort was concentrated on developing existing mathematical models for universal application. Therefore, this report contains the background material relevant to the handbook, describes the mathematical models used, and discusses the preparation of their respective inputs. These inputs vary with runway configuration, runway use, aircraft population, and operating rules (VFR or IFR). The airport surveys that were analyzed to provide input values and operating parameters are also described. An IBM 7090 Fortran program was written to automatically compute the inputs and model outputs in the form of delays versus operating rates and capacities of airport runway configurations. The use and application of this program is described.

4. Model Type: Quantitative; Probabilistic; Analytical; Computer Program described.

5. Features and Assumptions:

   Mathematical models provide a basis for evaluating aircraft delay versus operating rate for single runways and runway/taxiway crossings, for intersecting runways in VFR, for dual arrival feed in VFR to multiple runways, and IFR operations for all runway configurations. Poisson arrival distributions are assumed and service times depend upon the class of aircraft. Capacity is defined as the number of aircraft that can be serviced with an average delay of 4 minutes.

6. Major Results:

This report reproduces airport operations in terms of movement rate versus delay for the following situations: (1) Single, parallel, intersecting, and open V runway configurations, (2) VFR and/or IFR operations, (3) Runway/taxiway intersection crossings. The report is the foundation of AIL's Airport Capacity Handbook which is adopted by the FAA.

7. Documentation:

Incomplete - Program not included.

8. Completeness:

"There should be periodic reviews and data taking relevant to the models to periodically amend the handbook as new aircraft and control techniques are introduced".

9. Computer Implementation Requirements:

Simple. Computer program in Fortran for IBM 7090 exists.

10. Flexibility and Modularity:

Very realistic delay times computed for IFR operations. Can be included in wider scope.

11. Evaluation:

This report should be read, if for no other reason than it contains the mathematical methodology of the Airport Capacity Handbook which was adopted by the FAA. However, the mathematical procedures and documentation is virtually impossible to follow completely. Nevertheless, a general overview of the topic is easily obtained. The report defines capacity as the number of aircraft that can be serviced with an average delay of 4 minutes. This defining capacity as a function of delay is currently open to question.

1. Model: Final-Approach and Runway-Landing Capacity (B)

2. Identification of Related Report:

   Title: Analysis of a Capacity Concept for Runway and Final-Approach Path Analysis.

   Author: A.J. Goldman, et.al.

   Agency: National Bureau of Standards

   Report#: 10111

   Date: November 1969

   Other I.D. : Inter-Agency Agreement DOT FA69-WAI-166
   FAA Project No. 187-601-olR
   SRDS Report No. RD-69-47

3. Summary :

An analytical model for finding the capacity (defined here as "maximum throughput rate") of a runway used only for landings is described. An appendix relates the concept of capacity to the problem of estimating expected delays under steady-state conditions. A short simulation program is also included for the purpose of checking some analytical results.

4. Model Type :

   Quantitative, probabilistic; analytical. A simple computer simulation is also described.

5. Features and Assumptions:

   Minimum separation requirements both in the air and on the ground are considered as limiting runway capacities. In addition, buffer times between landings are allowed in order to compensate for errors. Discrete probability distribution for final-approach speeds is assumed. There is no mention of speed control, error variability with weather and equipment, and deviation from nominal approach speeds.

6. Major Results:

The primary results of the investigation is a closed form expression for estimating runway capacity under various conditions.

7. Documentation :

There is complete documentation in the report. Even the coding used in the simulation is listed.

8. Completeness :

No intent to continue the work is indicated, but suggestions are made for possible extensions of the results.

9. Computer Implementation :

Programming this model would not require much effort.

10. Modularity and Flexibility :

The model can be made more realistic with moderate effort. It can also be included in a package of wider scope.

11. Evaluation :

The model is of the same type as other probabilistic models described elsewhere (Blumstein, Harris, Odoni). It features should be considered for possible inclusion in future work.

1. Model: Sequencing of Landing Aircraft

2. Identification of Related Report:

   Title: Analysis of Sequencing Methods

   Author: R.S. Pardee

   Agency: The Thompson-Ramo-Wooldridge Products Company
   (FAA Contract # FAA/BRD-112)

   Date: June 1960

3. Summary :

The effects of four different sequencing logics on the landing capacity of a runway were studied. These logics were:

1) First come, first served.
2) First come, first served but constrained to land within fixed time slots.
3) Speed class.
4) Game sequencing where the system looked n moves into the future for the best sequence.

The resulting order of the logics by decreasing capacity was (3),(4),(1),(2). The other results were in the form of delays and landing intervals.

4. Model Type:

   Quantitative; Probabilistic; Simulation.

5. Features and Assumptions:

   The model assumes an approach speed population of nine acting over an eight mile common approach path. Constant approach speeds are assumed with each approach resulting in a successful landing. A three mile safety separation is used along with a single runway occupancy time for all landings. Departures are not considered. Each sequencing method is applied to a three hour traffic sample to obtain the results.

6. Major Results:

   The primary objective of the effort was to analyze the effects of various sequencing logics on single runway capacity. In addition to ranking these logics as mentioned in Section II (Summary) the investigator concluded that reasonable variations in common path length have relatively little effect on landing rate, but variations of the safety separation from three to two miles produces an increase of 35% in the landing rate; further, unless the safety separation is reduced from 3 miles it is pointless to consider landing rates that are greater than approximately 40 per hour. His effort also led him to conclude that sequencing by speed class does not result in any appreciable discrimination among aircraft types. Thus he emphasized the importance of increasing the accuracy of data gathering devices and terminal air traffic control systems so that the minimum separation standard can safely be reduced.

7. Documentation:

The report does not contain equations, flow charts, or a complete program. Instead it outlines the methodology and the computer program. The inputs were common path length, separation standards, approach speed population and the arrival distribution. The outputs were given as histograms for delays and landing intervals.

8. Completeness:

No model validation is mentioned in the report but the author remarks that the effort is continuing although there is little current evidence to support this.

9. Computer Implementation:

The model program was written in Fortran for the IBM 7090 it contains approximately 490 instructions comprising a main program and six subroutines.

10. Modularity and Flexibility:

The author claims that the program was written "in such a way that the addition of new sequencing methods will require a minimum of programming".

11. Evaluation:

This modeling effort assumes "that the errors in the system are zero and it therefore represents the theoretical best that can be obtained for any given sequencing method". Nevertheless the report is an informative basic approach to the problem of analyzing various sequencing logics. In its present elementary form, though, it can serve only as a guide or building block and it would be of little value alone.

1. Model : Operations Capacity, Single Runway

2. Identification of Related Report :

Title: Combined Landing and Take-off Capacity of a Single Runway

Author: J.F. Koetsch, Lt.Col., USMC

Agency: Federal Aviation Agency

Report #: Task No. 412-7-3R

Date: September 1960

3. Summary :

Abstract

This study presents a theoretical analysis of the landing capacity and the combined landing and take-off capacity of a single runway. The analysis takes into account that the landing aircraft are separated no less than a fixed distance on the approach leg and that the second landing aircraft does not land prior to the first landing aircraft having cleared the runway or prior to the departing aircraft having cleared the runwav. Also the departing aircraft is cleared for take-off only if the first landing aircraft has left the runway and the second landing aircraft will be equal or more than a certain distance from the taking-off aircraft prior to its commencing take-off roll. Interrelationships of the following factors are studied--the separation between pairs of landing aircraft; the runway occupancy time of landing aircraft; the distance of the gate at the start of the approach path from the end of the runway; the variation in approach speeds and take-off speeds consisting of a range about a mean approach speed(speeds are assumed to have a uniform distribution); and the distance between the second landing aircraft and the taking-off aircraft.

Results show the manner in which variations of the above quantities influence the landing and combined landing and take-off capacities of a single runway. Some deductions relative to the operation of multiple runways can be made as well as the logical steps by which the capacity of a single runway can be improved.

The work herein is the first step in an analysis in which the second step, now in formulation, will take into account the manner in which the capacities are influenced by errors in positioning.

4. Model Type : Quantitative; Probabilistic; Analytical.

5. Features and Assumptions : Aircraft arrive randomly for take-offs and landings. Landing aircraft have a uniform velocity distribution and this velocity is held constant during approach to touchdown. Constant runway occupancy time for landing aircraft. Minimum separation distance assumed at gate and runway threshold. Capacity (landing or take-off) is defined as 60/T operations per hour where T = average time interval (landing or take-off). T has dimensions of minutes. For take-offs intermixed with landings, the take-off capacity of a single runway is controlled or limited by the landing capacity.

6. Major Results : Landing capacity and combined take-off and landing capacity of a single runway as a function of several important variables is determined and comparisons are made for changes in these variables. These variables include the separation between pairs of aircraft, the runway occupancy time of landing aircraft, the distance of the gate at the start of the approach, path from the end of the runway, variation of aircraft speeds, and the distance between second landing aircraft and departing aircraft.

7. Documentation : Complete

8. Completeness : This work is the first step in an analysis in which the second step takes into account the manner in which the capacities are influenced by errors in positioning.

9. Computer Implementation : An analytical model, but computerization would be simple.

10. Flexibility and Modularity : Model is fairly realistic. Changes in parameters should be easy to institute. It can be included in a wider scope.

11. Evaluation : The report is concise and fairly easy to follow. Its main asset is in defining capacity as a function of the average time interval for an operation, rather than as a function of delay. The capacity, however, does not assume saturation of departing and landing aircraft. The variation of parameters which affect capacity is well developed. The report is based upon Blumstein's analysis of landing capacity, but it also adds the constraint of a minimum separation distance at the runway threshold.

1. Model : Operations Capacity, Single Runway

2. Identification of Related Reports:

   Title: A Digital Simulation of Airport Runway Utilization Comparing the Effects of Alternative Queue Disciplines and Various Types of Traffic Input.

   Author: G.L. Mallen

   Agency: Royal Aircraft Establishment

   Report #: Technical Note No. Math. 109.

   Date: August, 1964.

3. Summary :

   This report describes an effort to compare delays and queue sizes encountered by aircraft at a single runway facility by applying two alternative queue disciplines to three different traffic inputs. The work resulted from the author's familiarity with B.L. Marks' "Digital Simulations of Runway Utilization".

   Author's Summary

   Numerical models are described which simulate the way in which aircraft queues are formed at an airport runway. Traffic inputs for these models are constructed in the light of recent studies of traffic properties at London Airport. The utilization of a single runway, operated under the "first come first served" principle, is compared with that obtained by alternating landings and take-offs. The effect of a more regular time-table is briefly investigated.

4. Model Type :

   Quantitative; Analytical simulation

5. Features and Assumptions :

   The model has three basic components: a traffic input, a processor, and output. The traffic input is based on a particular London-Heathrow daily schedule. Three variations were used:

the published schedule with random deviations, regular arrivals within the hour, and regular arrivals over the whole day. The service times used were two minutes for a landing and one for a take-off with one minute intervals between successive take-offs. Separate processors represented the two queue disciplines. The "first come, first served" processor allowed traffic to use the runway in the order of request. The "alternate priority" processor sequenced users so that a landing followed a take-off whenever possible. Outputs of landing delay, take-off delay, landing queue length, and take-off queue length were displayed on accumulating histograms - one for each hour of the day. No allowance for service deviations, missed approaches, or airport dynamics was made.

6. Major Results :

Since the latter queue discipline eliminated the one minute runway idle period required between successive take-offs, it seemed likely that the model must prove this method to be more efficient. It did just that and specified delay reductions of 60% and capacity increases of 10%. The model also proved that there is no significant advantage in removing the short period "bunching" of users by uniformly scheduling them within the hour, but that there is great effectiveness in scheduling users over a larger 24 hour period. Unfortunately no details of model disposition or future advancement are indicated in the report.

7. Documentation :

The report contains no equations or program listing, but it does have definitions and informative flow charts.

8. Completeness :

The effort seems complete in that the author accomplished precisely what he set out to do. No real validation was attempted.

9. Computer Implementation :

The programs were written in the Autocode Language (CHLF 3 compiler) for the Mercury computer. It seems that the effort would not have been terribly complex with so few variables.

10. <u>Modularity and Flexibility</u>:

The model seems rather inflexible since it was designed only to prove specific relationships and not to facilitate system experimentation. Thus its addition to a larger simulation also may be of limited value.

11. <u>Evaluation</u>:

The effort of deriving delays and queue sizes in the air traffic system is certainly creditable, but the specific purpose of the model resulted in very limiting assumptions. The effort formally proved what may have been intuitive: reducing runway idle time increases capacity and spreading traffic evenly over large time periods does likewise. The real value, then, lies in the author's challenge to the currently sacred "first-come, first-served" queue discipline. Updating and expanding the model and transposing it to a domestic computer language may require considerable effort, however, to continue the challenge.

1. Model : Operations Capacity, Single Runway

2. Identification of Related Report :

   Title: Digital Simulations of Runway Utilization

   Author: B.L. Marks

   Agency: Royal Aircraft Establishment

   Date: 1964

3. Summary :

   The object of the work was to obtain insight into the behavior of runway queues using a digital computer. 300,000 take-offs and landings were simulated for this purpose.

4. Model Type :

   Quantitative; Probabilistic simulation

5. Features and Assumptions :

   The traffic input to the single-server queueing system was based on a particular, but typical daily schedule coupled with diminishing ranges of deviations from those scheduled times so that a Poisson distribution was approached. The model was designed to study just how the queue forming properties of the arrival process varied with the magnitude of the schedule deviations The server followed the "first come-first served" queue discipline, and constant service times were assumed. Other airport system dynamics were ignored in this basic model.

6. Major Results :

   For each simulated hour of operation histograms were kept for queue length, delay, inter-arrival times and number of arrivals in the hour. The first run used a completely random arrival process while subsequent runs introduced a scheduled process. The resulting trend was decreasing congestion with increasing regularity in the arrivals. Later runs showed that variations in traffic demands are rapid enough to make queues at peak periods significantly different from those associated with steady states at the same level of demand. One other pertinent result was a realization by the author that abandonment of the "first-come, first-served" queue discipline may also reduce congestion. This observation was the basis of G.L. Mallen's work, "Digital Simulation of Airport Runway Utilization Comparing the Effects of Alternative Queue Disciplines and of Various Types of Traffic Input".

7. Documentation :

The report is very descriptive but it omits flow charts, equations, and program listing. Instead it includes only graphical illustrations of the major results.

8. Completeness :

The author gives no indication of continuing the effort nor does he describe any attempts for validation of his idealized model in the report.

9. Computer Implementation :

The model was developed in the Autocode language for a Ferranti Mercury computer. The author advises that "To extend the Autocode translator and incorporate a full simulation language would have been a considerable task".

10. Modularity and Flexibility :

The researcher prepared several sub-routines to provide the facilities in the model and he feels that his "kit of parts" offers great advantages in simplicity of program construction and flexibility.

11. Evaluation :

Suitable results emerged from this effort and they are substantiated by similar domestic projects. Thus there seems to be no distinct advantage in adopting this foreign model for traffic simulation.

1. Model: Runway/Final - Approach Model (B)

2. Identification of Related Report:

   Title: Analysis of Alternatives for Increasing Runway Capacity and Reducing Terminal Area Delays.

   Author: Milton B. Meisner

   Agency: Federal Aviation Administration

   Report#: A68-24652

   Date: October, 1967

3. Summary:

Abstract

This paper examines the capacities of various runway configurations and the delays that can be expected as aircraft operations increase. Benefits in terms of increased airport capacity are given for other alternatives. These include reduced radar spacing, computer-aided final approach spacing, sequencing by aircraft speed classes, segregation of aircraft on different runways by aircraft performance characteristics, and more uniform scheduling of operations at airports.

4. Model Type: Quantitative; Probabilistic; Analytical.

5. Features and Assumptions:

   Capacity computations were done using the methodology of the FAA's "Airport Capacity Criteria Used in Preparing the National Airport Plan". Using this methodology, the capacities are based on a four-minute delay to arrivals or departures, except that VFR arrival capacity is shown at a one-minute arrival delay. The data excludes the effects of airspace regulations. Capacities are computed assuming two different compositions of aircraft traffic.

6. Major Results:

   Alternatives for increasing airport capacity and reduction of delay are compared in terms of effectiveness, without concern for the acceptability or practicality of the alternatives. It is found that new runways or airports increase capacity most, followed by automation and procedural changes, then scheduling changes then segregating runway operations due to aircraft performance characteristics, then reduced radar spacing and finally improving taxiway configurations.

7. Documentation: Complete.

8. Completeness: The model is complete.

9. Computer Implementation:

   Some simulation was used to determine capacity increases, but no program or flow chart is included.

10. Flexibility and Modularity:

    The results are easily adaptable to changes in the method of capacity computation.

11. Evaluation:

    The effectiveness of different alternatives in increasing airport capacity is shown to agree with one's intuitive feeling. Costs of acceptability are not considered. Also, all computations are based upon the assumption that capacity is a function of delay, an assumption which is currently open to question.

1. Model: Runway Final Approach

2. Identification of Related Report:
   Title: Traffic Generator and Basic Approach and Landing Simulation
   Author: The MITRE Corporation
   Agency: The same
   Report#: Project No. 1223 (Sponsor: NASA ERC)
   Date: June 1969.

3. Summary:

   MITRE has undertaken the development of tools for analysis and evaluation of electronic elements of air transportation operational support systems. Two such tools are a Traffic Generator that creates simulated merging air traffic under a variety of conditions and Basic Approach and Landing Simulation, BALSIM, that models the traffic and environment for approaches and landings at a generalized terminal. The first tool is planned for use with programs developed by other contractors. Typical programs are Proximity Warning Indicator analysis and a more generalized hazard avoidance analysis. This generator is not designed to stand alone, but to interface with other models. Alternately the second tool is considered to be the basic building block which will operate in an independent condition to experiment with the effect of any present or proposed electronic subsystem in a simulated complete terminal air traffic environment.

4. Model Type:

   Both models involve probabilistic approaches to simulations with the intention of deriving quantitative and qualitative results.

5. Features and Assumptions:

   The Traffic Generator has been designed to create and fly simulated aircraft within an airspace of 15 miles square in which two streams of aircraft merge. This is accomplished with three main modules: aircraft utilization, generation, and output. In the utilization module aircraft types, entry headings, and velocities are specified. The generation module controls the selection of error values appropriate to each aircraft plus the definition of its basic flight course through the system. Then the position and altitude of each aircraft are calculated at the end of every second of simulation.

The BALSIM contains a characteristics processing module, an aircraft generation module, an operating module, and a report generator module. The geography of the model is described as a single runway with left and right "trombone-slide" approaches.

6. Major Results :

The results of the project described in this review are the two models themselves; no experimentation is involved.

7. Documentation :

Reports containing descriptive data and computer programs are available from MITRE for both of these simulations.

8. Completeness:

MITRE has completed their development of these models; validation, application, and experimentation are underway.

9. Computer Implementation:

The General Purpose Simulation System (GPSS) was chosen for both models for several reasons: the language is available on both the IBM 7094 and 360 computers; efficient simulated vs. real time requirements; ease in programming; MITRE staff preference. The programs are available from MITRE.

10. Modularity and Flexibility :

Both models were built so that a variety of parameters could be applied; therefore they are modular and flexible.

11. Evaluation:

Little detailed information concerning these models is readily available outside of MITRE, but more detailed descriptions may be available from the contract sponsor.

1. Model: Operations Capacity, Single Runway

2. Identification of Related Report :

   Title: "An Analytic Investigation of Air Traffic in the Vicinity of Terminal Areas".

   Author: A.R. Odoni

   Agency: M.I.T.

   Report#: Operations Research Center #46

   Date: December, 1969.

3. Summary :

A single runway which is used exclusively for departures is examined first. Analytical expressions for the maximum throughput rate under saturation conditions are derived.

The conceivable situation in which landings alternate with take-offs is also investigated. Again expressions for runway capacity are derived and the importance of accurate control of spacing on final approach is underlined.

Finally, the possibility of inserting departures between successive arrivals at a runway, when a long enough gap exits, is examined in detail. Several parameters of interest associated with this situation are computed. Some numerical results are presented along with a qualitative discussion of various issues.

4. Model Type :

   Quantitative; probabilistic; analytical.

5. Features and Assumptions :

The departure capacity of a runway is a function of the time needed to set up for a take-off, the response time of aircraft, and the runway occupancy time during departures. Probabilistic distributions for these quantities are assumed. No queuing analysis is performed .

When departures and arrivals are alternating, a random variable that accounts for spacing errors on final approach is included. The sequence of events that take place in this situation is modelled.

A model, similar to the ones commonly used for automobile traffic, is introduced for the case in which departures are inserted between successive arrivals. The expected waiting time for a single departing aircraft is obtained.

6. Major Results :

Expressions for the capacity of runways used for departures only, and for arrival-departure-arrival sequences. Expected delay of departure at a runway which is used primarily for arrivals. Numerical examples of the application of these expressions.

7. Documentation :

Complete and detailed description of the model and of the derivation of the various formulae.

8. Completeness :

This is a final thesis report. No model validation with real data was attempted. However, the numerical results that the models give for typical sets of condition are very reasonable.

9. Computer Implementation :

Very simple. Analytical expressions are provided and can be used directly in the computer program.

10. Modularity and Flexibility :

The models can be easily incorporated in a larger system and are usable with any set of local conditions.

11. Evaluation :

The models discussed here can serve as building blocks in large simulation efforts aimed at representing operations at runway complexes.

The approach demonstrates the usefulness of applied probability theory in this area. An important gap in the analysis is the lack of a queuing model for a runway which is used only for departures. This gap is due to the fact that because of the peculiar pattern of the generation of departures at airports, the mathematics of a queuing-type analysis become intractable. A simulation study may, therefore, be needed at this stage.

In summary, the models discussed here should be studied before proceeding to further work.

1. Model: Landing Capacity & Queuing, Single Runway

2. Identification of Related Report:

   Title: "An Analytic Investigation of Air Traffic in the Vicinity of Terminal Areas"

   Author: A.R. Odoni

   Agency: M.I.T.

   Report#: Operations Research Center #46

   Date: December, 1969.

3. Summary:

A single runway which is used exclusively for landings is examined. The probability distribution for the length of the interval between landings under saturation conditions is obtained. The inputs to the model are the velocity distribution of incoming aircraft, the distribution for the errors in spacing aircraft and the minimum separation requirements, both in the air and on the ground.

A queuing analysis is subsequently performed and an original method for modelling the arrivals queue is developed. The derived expressions for average delay per aircraft and runway utilization differ from the expressions for the M/G/1 queue which are often used in this area. Numerical results are derived for the throughput rate and average delays for typical sets of conditions.

4. Model Type: Quantitative; probabilistic; analytical.

5. Features and Assumptions:

   Capacity is defined as a maximum throughput rate under saturation conditions. The model assumes that each given aircraft maintains a constant approach speed throughout the final approach path. Wind conditions can be taken into consideration by modifying the probability distribution for final approach speeds.

   The model does not make provisions for estimating the probability of a missed approach. However, a random variable which demonstrates the possible effects of spacing errors due to the pilot or the controller is included in the model.

The queuing analysis is performed for steady state conditions Poisson (random) arrivals are assumed at the periphery of the terminal area.

6. Major Results :

Method of estimating expected capacity and variance of the capacity under saturation conditions for any given set of parameters. Steady-state expressions for average queue length, average number of a/c in the queue and runway utilization rate for different levels of traffic density. Parametric analysis of sensitivity of the results.

7. Documentation :

Complete and detailed description of the model is provided. A program for computing the numerical results is mentioned but not listed. Results are presented in equation, table, or graph form.

8. Completeness:

This is a final thesis report. No model validation was attempted. However, the numerical results that the model gives for typical sets of conditions seem very reasonable.

9. Computer Implementation:

It is very simple to write a computer program that provides numerical results based on the derived formulae. Such a program was written by the author in FORTRAN and run at the M.I.T. Information Processing Center.

10. Modularity and Flexibility :

The model can be easily incorporated in a larger system and is usable with any set of conditions.

11. Evaluation :

The present model is an extension of Blumstein's work (see evaluation). This extension takes account of errors and inaccuracies in the final spacing process. In this respect, the current model contains a unique feature.

On the other hand, the derived formulae are more complicated and more difficult to use than those derived by Harris or by the National Bureau of Standards. In addition, the model should be improved to provide estimates of missed approach probabilities.

The queuing model appears to be the most realistic one available for steady-state conditions. However, it suffers from the usual problems associated with the steady-state type of analysis.

In summary, this model must be studied carefully before further work in this area is undertaken.

1. Model: Landing Queues, Single Runway

2. Identification of Related Report:

Title: Delays to Aircraft Serviced by the Glide Path

Author: Robert M. Oliver

Agency: Institute of Transportation and Traffic Engineering
University of California, Berkeley

Report: Printed in Operational Research Quarterly,
Volume B. No. 2, June 1962.

Date: June, 1965

3. Summary:

Abstract

This paper considers some of the statistical service, flow and delay problems which arriving aircraft encounter in the glide path of an airport runway. Mathematical expressions for service time distributions and delays are formulated in terms of the probability distributions of spacings between discharges of the glide path. In this paper the author also considers some numerical solutions of the average glide path separation as a function of W, the average delay to arriving aircraft, X_0, a minimum glide path separation and λ the average Poisson flow rate.

4. Model Type: Quantitative; probabilistic, analytical.

5. Features and Assumptions :

This report works on Blumstein's analysis that the greatest improvement in landing capacities of a single runway under typical IFR conditions can presently be obtained by reducing the average spacing of aircraft in the glide path. The report assumes a single-channel Poisson-fed queue model. The report also assumes that the probability that the spacings between discharges is given by a translated-exponential distribution.

6. Major Results :

The report outlines a method which determines the average service time for an average delay (Even without a translated-exponential distribution).

7. Documentation : Complete

8. Completeness:

This report is not extensive. It is a beginning approach to the delays occurring in the glide path and thus can be extended by further work.

9. Computer Implementation: Simple.

10. Flexibility and Modularity :

This model may be included in a model of a wider scope

11. Evaluation :

The model is a straight-forward application of a Poisson-fed queue to the glide path. This is an excellent example of the Operations Research approach to aircraft delay. However, this approach has been superceded by later models, and therefore has little practical value.

1. Model: Missed Approach Model

2. Identification of Related Report:

Title: A Theoretical Determination of the Probability of a Missed Approach Along the Common Glide Path.

Author: H.I. Ottoson

Agency: Research Division, Bureau of Research and Development, FAA.

Report#: 6

Contract#: BRD-112

Date: September , 1960.

3. Summary :

This model is beneficial in concept and operational analysis, and is related to those models built for determining the capacity of the common path.

Abstract

In order to obtain a more realistic measure of the theoretical average landing rate, some estimate of the effect of aircraft control error and the attendant wave-off likelihood must be made.

It is therefore the purpose of this report to present one method of determining the missed approach probability as a function of the magnitude and variance of the control errors and the other parameters of the IFR landing procedure. This determination will allow the investigation of the effect of each of the various control errors and each of the system parameters on the missed approach probability.

4. Model Type:

Quantitative, Probabilistic, Analytical.

5. Features and Assumptions:

The model assumes that the runway is used for landing only, aircraft are always available at the gate of the common path, and that aircraft speed and gate error have a uniform distribution.

6. <u>Major Results:</u>

The description of a model for the common path, the derivation of formulae for the missed approach probability for all possible cases (for the distribution functions assumed), and a parametric sensitivity analysis that shows that the range of the gate delivery error is the dominant factor in determining the missed approach probability. (See B-7).

7. <u>Documentation:</u> Well documented.

8. <u>Completeness:</u>

This is a final model, but, as the author states, the ultimate desired result is to find the effect of the missed approach probability on the theoretical landing rate.

9. <u>Computer Implementation:</u>

An IBM-709 program was written to compute numerical results for different values of the parameters. The program used determines the effect of each of the system parameters on the missed approach probability.

10. <u>Flexibility and Modularity:</u>

This model is intended to be included in a larger system for determining the capacity of the common path (landing rate).

11. <u>Evaluation:</u>

This is a good model that should be studied by all those interested in terminal area operations, and more specifically, in the common path. The results obtained are of great value and show the importance of using an additional separation between aircraft above the minimum separation required by FAA regulations in order to reduce the missed approach probability (when this additional separation is zero, the model gives a missed approach probability of almost 0.5 for real values of speed and common path length). It would be interesting and useful to analyze how this additional separation effects the capacity of the common path (or landing rate).

1. <u>Model</u>: Gate Errors

2. <u>Identification of Related Report:</u>

   Title: Sensitivity of a Terminal Area Control Concept to Uncertainties in Control Information.

   Author: Harold I. Ottoson

   Agency: MITRE Corporation

   Report#: 9260

   Date: March 1969

   Contract#: DOT-FA69NS-162

   Contract Sponsor: FAA

3. <u>Summary</u>:

This is a paper concerned with the results obtained from a simulation model for determining the standard deviation of the schedule error at the gate. Only an outline of the model is given in the paper.

4. <u>Model Type:</u> Quantitative; Probabilistic; Simuation.

5. <u>Features and Assumptions:</u>

   The model assumes a normal distribution specified by a mean and a standard deviation for each random variable and that wind is independent of time and altitude. It does not reflect how real pilots will fly (turn rate tolerance, velocity tolerance, acceleration tolerance, etc.) in changing wind conditions along the flight path.

6. <u>Major Results</u>:

   The parametric sensitivity analysis shows how the uncertainties in the inputs to the computer computation will affect the standard deviation of the schedule error at the gate.

7. Documentation:

Little information about the actual model is given, but the documentation concerning definitions of parameters, variables, and effectiveness measures is good.

8. Completeness: A final report.

9. Computer Implementation:

Although this is a Monte Carlo simulation model, no mention of computer implementation is made.

10. Flexibility and Modularity:

There are little possibilities of extending the model of including it in a larger system.

11. Evaluation:

Unfortunately this paper does not contain the description of the model to the extent needed to be worth studying. The results showed that marked improvement in the accuracy of individual items of control information does not necessarily improve control precision when the precision of the other items is dominating.

1. Model: Time-Dependent Queues at a Runway

2. Identification of Related Report:

   Title: A Study of Air Traffic Control System Capacity

   Author: Gordon Raisbeck, B.O. Koopman, et. al.

   Agency: Arthur D. Little, Inc.

   Report #: FAA-RD-70-70

   Date: October 1970

   Other I.D.: Contract No. FA70WA-2141

3. Summary:

   The time-dependent single queue analysis examines queues at a single runway used for landings. Double queues involve runways used for mixed operations with a variety of arrival vs. departure priority rules.

Abstract

The mathematical theory of time-dependent queues has a number of applications to air traffic control system capacity, but available mathematical resources have not been turned to this purpose. We have identified a class of time-dependent queueing problems with periodic demand and service functions, such as one might use to represent diurnal variations in demand and demonstrated some general properties of their solution. In particular, we find that a large class of such problems admits a unique and stable periodic solution.

With the aid of machine computation, we have calculated some of the statistics of a number of time-varying single queues to illustrate dynamic properties not accessible by steady-state analysis. We have also formulated differential equations for double queues with several priority rules.

4. Model Type: Quantitative; Probabilistic; Analytic. The differential equations for the time-varying single queues have been solved by using numerical techniques with the aid of a digital computer.

5. Features and Assumptions :

Random (Poisson) arrivals and negative exponential service times are assumed for runways. The arrival rate is allowed to vary as a function of time (of the day). A maximum allowable length of the queue is postulated (the finite queue assumption is necessary in order to obtain a numerical solution through machine computation). Differential equations are then written for single and double queues, and numerical solutions are obtained for the single queue case for a variety of parametric assumptions.

6. Major Results :

Differential equations describing single and double time-varying queues, and closed form expressions for some interesting queue statistics. Numerical solution of single queue equations.

7. Documentation :

There is complete documentation of the analytic part of the study. Standard computer programs for the solution of systems of first order differential equations were presumably used,but these programs are not discussed.

8. Completeness : An interim report. This study is continuing.

9. Computer Implementation : Simple for the assumptions made. However as the number of equations and their complexity increases,serious computer time and memory space limitations may arise.

10. Flexibility and Modularity : The model is very general and can be adopted to any number of conditions.

11. Evaluation:

This is an excellent "first cut" at analyzing time-varying single queues at runways. Although the model at its present stage provides only a first order approximation to reality, it makes it possible to observe (and predict)such important phenomena as the build-up of queues and the effects of a sudden disruption of service on waiting times. Some weaknesses of the model include: (a) The assumption that aircraft which find the queue at its maximum length are turned away (diverted); this is clearly unrealistic,but can be easily corrected during a second effort. (b) The assumption of negative exponential (Poisson) service is also unrealistic and tends to lead to an overestimation of delays. However, change of this assumption would immensely complicate the mathematical formulation of this model and may lead to unacceptable expenses in terms of computer time spent on producing numerical solutions.

The mathematical model for double queues is of much more doubtful practical significance. The system of equations may be too long for even moderate size queues. In addition, it is felt here that by assuming exponential service times for departures and Poisson generation of departures at the runway, the model is probably oversimplified to an unacceptable degree.

In general, it is recommended that the two models which are reviewed here (Chapter 6 and Appendix B of the report) be given serious study.

1. Model: Runway/Final Approach

2. Identification of Related Report:

   Title: Aircraft Sequencing, Parallel Landings and the TMA Route Structure

   Author: S. Ratcliffe

   Agency: Royal Radar Establishment U.K.

   Report: # A68-24642

   Date: October, 1967

   Other I.D. Conf. 17/W.P.-61, PAA-46 (IATA)

3. Summary:

Abstract

ATC techniques have adapted themselves to the limitations of existing radar, ILS, and other navaids. The present paper draws preliminary conclusions from a study of the possible pay-off from improvements in sequencing techniques, runway utilization, and TMA routings which might be possible if all the existing electronic limitations could be eliminated.

4. Model Type: Qualitative, Probabilistic, Analytical.

5. Features and Assumptions:

   This paper assumes the standard ATC rules for the United Kingdom to be in effect, and considers variations in glide path and stacking patterns. Radar limitations are then ignored, and terminal area traffic is diagnosed.

6. Major Results:

   The report takes present day air traffic control techniques and examines qualitatively, the advantages and drawbacks of various terminal area operational procedures.

7. Documentation: Complete

8. Completeness: This is a working paper and merely presents preliminary results.

9. Computer Implementation: Simple.

10. Flexibility and Modularity:

    The results of this paper can be included in a larger model.

11. Evaluation :

The report is not very technical and merely discusses, rather than shows, the points that are being presented. It is a brief paper, entered as a working paper to a conference in the United Kingdom .

1. Model: Landing Capacity - VFR

2. Identification of Related Report :

   Title: An Analytical Investigation of Air Traffic Operations in the Terminal Area.

   Author: Robert W. Simpson

   Agency: M.I.T.

   Report#: Ph.D. Thesis

   Date: August 1964.

3. Summary:

This review is concerned with a model for landings under good weather conditions. It assumes that the runway is used for landings only and that there is no wind present.

Abstract

The VFR square pattern landing system, or "trombone" can be studied analytically if certain idealizations are made regarding pilot decisions and aircraft speeds. The results give a closer insight into the mechanism of operation of the most common and most successful approach regulator.

The model very closely describes the process which actually occurs in a VFR circuit, particularly at a military training aerodrome where new pilots use rules of thumb to help their spacing judgement.

4. Model Type: Quantitative, Probabilistic, Analytic.

5. Features and Assumptions:

   The model assumes a runway that is used for landings only, a first-come, first-serve discipline for arrivals, and all aircraft have the same ground speed. Assuming a Poisson distribution of arrivals , the mean trombone position and the probability of an aircraft using the normal path at different traffic loads are derived for steady state conditions, and making use of these, the landing time distribution is obtained.

6. Major Results:

The probability of an aircraft using the normal path and the mean trombone position are plotted versus the mean arrival interval in one graph, and versus the arrival rate (capacity) in another. The cumulative distribution of VFR arrival interval is shown graphically comparing sample results with theoretical model results.

7. Documentation: Complete

8. Completeness: A Final report.

9. Computer Implementation:

No implementation is done, but it would be simple to write a computer program for this model.

10. Modularity and Flexibility:

It is possible to extend this model by assuming a distribution of t_o (the lateral time-space from the runway that all aircraft must fly), or by assuming a distribution of velocities. This model can easily be included in more general systems.

11. Evaluation:

This is a good analytical model that permits the understanding of the landing procedure under good weather conditions. The numerical results that are given show a reasonable agreement between the model output and actual data. It is important to mention that the model does not consider minimum legal separations between consecutive landing aircraft.That coupled with the fact that VFR aircraft do not fly a straight-in approach to the runway but submit to entering a landing pattern which is approximately 5 minutes in length, would introduce further delays decreasing the capacity of the system.

The model indicates that there is a capacity limit to the trombone regulator which is not equal to the runway capacity.

This report provides a good starting point for further research in this area.

1. Model: Parallel Landings

2. Identification of Related Report:
Title: Theoretical Minimum Separation of Parallel Runways
Author: Warren Taylor, Earl K. Yost, Phillip S. Ball, Jr.
Agency: FAA Bureau of Research and Development
Date: May 1960

3. Summary :

Author's Summary

The Operations Analysis Division of the Bureau of Research and Development was asked in October 1958 to develop a plan for determining the minimum separation of dual parallel runways for independent IFR operations....

The objectives of the Operations Analysis phase, aimed toward a determinination of operational minimum spacing criteria, were: (1) determine the theoretical spacing; (2) recommend the objectives for a simulation phase by Systems Analysis; and (3) recommend the objectives for a flight test phase at NAFEC.

The work of the Technical Development Center and of Air Traffic Management of O'Hare Airport in Chicago was reviewed and variables were listed. Mathematical models or formulae were derived relating the variables to a suitable "yardstick" or measure of effectiveness. Calculations were made with field data as inputs and theoretical results and conclusions were developed....

4. Model Type:
Quantitative; Probabilistic; Analytical.

5. Features and Assumptions :
The basic model assumes a normal distribution of deviations from the parallel runway centerlines in the horizontal plane. Criteria for collision of two approaching aircraft were established by examining in detail the area common to both distributions. The model was then extended into the third dimension by assuming that the lateral and vertical

deviations from the runway centerlines are independent.

Next, one collision in an estimated fifty million total IFR busy hour landings at all major U.S. airports from 1960 until 2000 was selected as the acceptable collision rate. Further it was assumed that aircraft positions would be randomly distributed in the longitudinal direction of flight. Lastly the weakest assumptions dealt with technology of the early sixties: (1) the largest aircraft size considered was the equivalent of a B-52 and (2) radar data was considered accurate to within ± 50' laterally and ± 10' vertically.

6. Major Results:

It became evident that the separation was most sensitive to the standard deviation of the distribution of lateral navigation errors (σ_y) and that it was influenced to a lesser degree by the vertical error distribution, aircraft size, number of landings per potential collision and so on. Using the largest (most conservative) value of the lateral standard deviation encountered in the observed data (σ_y = 525') minimum separation was calculated to be 3650'. Further the authors concluded that if the effect of navigation inaccuracies due to overshoot of runway centerline in the turn-on area were in some manner eliminated, minimum separation could be reduced to 2700'. But the authors were quick to point out that this general solution should not be applied automatically to every airport and that human factors and radar procedures must be examined. Finally the general effect of adding an independent runway to an airport having single runway operation was estimated as reducing the landing and take-off delays to values somewhat below 50% of single runway delays.

7. Documentation:

The report includes definitions of variables, identification of data sources, explanations of pertinent assumptions, and mathematical derivations.

8. Completeness:

The authors gave no indication of continuing effort, but they advocated a rigorous flight evaluation for validation.

9. Computer Implementation:

This model was not developed for a computer, but there should be little difficulty in programming the model to derive solutions for a variety of conditions.

10. Modularity and Flexibility:

The intent and nature of the development of the model make it rather inflexible for considerations involving other than parallel flight paths.

11. Evaluation:

This report is certainly worthy of attention. It begins with reasonable assumptions and proceeds to logical conclusions. The assumptions are supported and the methodology is explained; thus the results are justified. The basic model and the methodology could be combined with current parameters to derive a value based on our new technology. In addition to its technical validity the publication contains useful summaries of controversial safety issues which add to its overall excellence.

1. Model : Terminal Area

2. Identification of Related Report:

   Title: Delays in Terminal Air Traffic Control

   Author: Robert M. Oliver

   Agency: Institute of Transportation and Traffic Engineering, University of California, Berkeley

   Report: Printed in *Journal of Aircraft*, Vol. 1, No. 3

   Date: March, 1964

3. Summary :

Abstract

In this paper delay problems where departures and landing operations are performed on a runway or within the glide path of a terminal air traffic system are studied. The distribution of delays, the number of delayed aircraft, and the effect of multiple streams feeding the service system are discussed. Delay models include cases where two priority classes are serviced by one runway. The conditions under which the highest priority leads to lowest expected costs or average delays are also discussed. Priorities are established such that aircraft having a service time less than a critical value are placed in top priority. The analysis extends to more than two priority classes within a stream of landing and departing aircraft. Delay models are discussed which include, in addition to the usual assumptions about service times, the additional features that constant minimum spacings must be maintained between all users of the runway or glide path and that low priority aircraft are interposed between high priority aircraft. Delays due to self-clearing rules are discussed; long runs of one type of aircraft follow long runs of another type of aircraft until all queues are completely dissipated.

4. Model Type: Quantitative; Probabilistic; Analytical.

5. Features and Assumptions :

   The report assumes the aircraft arrivals are Poisson and service times are assumed to vary due to the type of aircraft. A priority system of serving the aircraft with the lowest service time first is utilized initially. Different priority systems then examined for landing only and both landings and departures.

Minimum separation distances are taken into account.

6. Major Results :

   The report concludes that a priority system based upon average service times or cost should be implemented for best results in terminal air traffic control.

7. Documentation : Complete

8. Completeness:

   This report offers suggestions to improve terminal air traffic control, but more research is definitely required before implementation.

9. Computer Implementation : Simple.

10. Flexibility and Modularity : This model can be included in a model with a wider scope.

11. Evaluation:

    This effort is an excellent example of the Operations Research approach to the problem of aircraft delay in a terminal area. The model presented here has since been superceded by more recent models, but the report could be read to obtain an idea of the "classic" Operations Research model.

OVERVIEW

Category C - Terminal Area Models

This section considers models of terminal areas as a whole, as well as models of sub-elements of the terminal area other than those examined under Categories A and B (surface traffic, runway/final approach).

Analytical or simulation models of air traffic movement in a given metropolitan area (e.g. New York) are reviewed here. Such models (usually simulations) investigate the sensitivity of area capacity and congestion-related delays to modifications of local area control procedures as well as to the possible construction of a new airport or new runways in the metropolitan area in question.

Other models, also included here, concentrate on some specific aspect of the operations that take place after an aircraft has entered the terminal area and before it reaches the final approach. It should be underlined that a considerable number of rather complex models must be combined in any realistic analysis of terminal areas. These include models of the holding stack, of the regulator space and the funnel, of aircraft spacing and sequencing procedures in the terminal area, and of communications load as a function of traffic density.

Analytical models for the terminal area as a whole are scarce, primarily because of the complexity and multitude of interaction that take place prior to the final approach stage of a flight. Warskow describes the basic techniques developed at AIL, in this respect, and an application of this methodology to the New York terminal area can be found in Faison's report from NAFEC. The report by Carlin and Park should also be studied here.

Simulation models of the terminal area are, apparently, more numerous although, for proprietary reasons, it is often difficult to obtain precise information about these models. Of the reports studied here, the simulation described by the National Bureau of Standards (DELCAP) and by Simpson are outstanding. The first concentrates primarily on a quite realistic simulation of airport operations while the second provides a very explicit outline of operations in the pre-final-approach area. A model developed by General Precision Systems, Ltd., has been used by SRI for the Chicago area. A MITRE Corporation model by Keenan and Barnsby is also reviewed. Very realistic real-time simualtions can be performed at the NAFEC facilities at Atlantic City. The report by Slattery describes a typical such simulation, in this case for the New York terminal area.

Of great interest in the past, have been the ideas of sequencing, spacing, and flow control in the terminal area. Reports by Jolitz, Ingram, and Pardee are reviewed here. This section also describes two models of the holding stack by Simpson.

Category C

Terminal Area Reports

	Review Number
Alexander, L.T., Ash, M., "Terminal Air Traffic Control: A Laboratory Model for Man-Machine System Research"	
Alexander, L.T., Cooperband, A.S., "A Laboratory Model for Systems Research: A Terminal Air Traffic Control System"	
Alexander, L.T., Porter, E.H., "Terminal Air Traffic Control and Problems of System Design"	
Carlin, A., Park, R.E., "A Model of Long Delays at Busy Airports"	C-11 F-3
Faison, W., Meisner, M., Van Duyne, E., "Alternative Approaches for Reducing Delays in the Terminal Areas"	
Faison, W.E., Meisner, M.B., Petersen, P.H., Given, J.J., Slattery, H.F., "Analytical Study of Air Traffic Capacity in the New York Metropolitan Area and New York Air Traffic Capacity Study"	C-12
Hall, S., "A Simulation of the Airside Traffic at an Airport"	C-14 A-5
Holland, F.C., Analysis Tools for Airport Capacity"	
Holland, F.C., "Computer Sizing of Terminal Area Command and Control for the ATC Advisory Committee"	

	Review Number
Holland, F.C., Garceau, T.V., "Genealogy of Terminal ATC Automation"	
Hooten, E.N., Burns, H., Warskow, M.A., "Operational Development of Techniques for Computing Airport Capacity"	
Hooten, E., Pogust, F., "Terminal Area Traffic Sequencing ... Some Guidelines for Computer Design"	
Hosford, J.E., "Simulation by Incremental Stochastic Transition Matrices"	C-17
Ingram, G.W., "The Terminal Air Traffic Scheduling Model"	C-7
Jackson, A.S., Morse, R.V., Crocker, J.P., "A Fast Time Simulation Model of Automated Terminal Area ATC Systems"	C-2
Jolitz, G.D., "Flow Control - An Investigation of A Technique for Predicting Demand and Service at the Terminal Facility"	C-10
Keenan, J.A., Barnsby, A.E., "Functional Description of Basic Terminal Approach Simulation Model"	C-16
Martin, D.A., Willett, F.M., "Development and Application of a Terminal Spacing System"	
Moore, J.K., Hosford, J.E., et.al., "Air Terminal Study"	
Morse, R.V., Crocker, J., "A Study of Terminal Area Control Logics and Geometries Using Fast Time Simulation"	

Reference	Review Number
Ottoson, H.I., "An Investigation of the Expected Magnitude of Control Errors in The TASC I System Transition Area"	C-6
Pestalozzi, G., "Delays to Air Traffic in a Terminal Area"	
Porter, L.W., "On Optimal Scheduling and Holding Strategies for the Air Traffic Control Problem"	
Price, S.P.E., "Queueing Theory in Fast Time Simulation of Air Traffic Control"	
Ratner, R.S., "A Methodology for Evaluating the Capacity of Air Traffic Control Systems"	C-3
Short, E., Steele, W., Gilsinn, J., Klauun, D., "DELCAP: A Simulation Model for Estimating Terminal-Area Throughputs and Delays"	C-5
Simpson, R.W., "An Analytical Investigation of Air Traffic Operations in the Terminal Area"	C-1 C-8 C-9
Simpson, R.W., "Fast Time Simulation of a High Performance Terminal Area Traffic Control System"	
Slattery, H.F., "New York Air Traffic Capacity Study"	C-4
System Development Corp., "Description of the Terminal Air Traffic Control Laboratory System"	
Warskow, M.A., "Techniques Useful in the Assessment of Terminal Area Design and Capacity"	C-13
Warskow, M.A., Hooten, E.N., Burns, H.C., "Design For the Future in Terminal Air Traffic Control"	

	Review Number
Warskow, M.A., Wisepart, I.S., "Capacity of Airport Systems in Metropolitan Areas"	C-15
Winick, A.B., "Area Navigation and the Relationship to Terminal Area Capacity"	

1. Model: Simulation of operations in terminal area.
2. Identification of Related Report:
   Title: An Analytical Investigation of Air Traffic Operations in the Terminal Area.
   Author: Robert W. Simpson
   Agency: M.I.T., Dept. of Aeronautics & Astronautics
   Report#: None (Ph.D. Thesis)
   Date: August, 1964.
3. Summary:
   The fourth chapter of this report describes the simulation of operations in the terminal area. The simulated region begins at the periphery of the terminal area. The movement of a/c from that point to the runway is simulated and appropriate statistics are collected and presented. Although the model includes neither take-offs nor multiple runway effects, it is otherwise detailed enough to present a realistic picture of the sequence of operations in the terminal area.
4. Model Type:
   Quantitative; simulation; some variables are deterministic and some are probabilistic .
5. Features and Assumptions:
   The procedures and terminal area configuration assumed in this model are different from the current ones in many respects. The primary difference is that traffic arrivals are metered from entry-fix holding patterns to a single landing stack located at the ILS gate. The landing stack is not the usual racetrack pattern, but a "semi-orbital" pattern of 1.2 minutes radius.
   A single runway is assumed and departures are not allowed. On the other hand, the model includes wind effects, communications workload, and control and navigation decision-making.

The primary objective of the model is to demonstrate the usefulness of the fast simulation concept through a detailed case study. Therefore, the specific terminal area configuration that it studies must be viewed as only one of many possible alternatives that can be investigated by using the simulation techniques.

6. Major Results:

The major result is the simulation program itself. It demonstrates that a realistic computer simulation of terminal area events is indeed possible. It also shows the considerable amount of detail that must be included in such a model.

The computer program was not put to any further use after the completion of this report.

7. Documentation:

A detailed and clear description of the model is provided; examples of computer input and output are shown; no computer program is listed and neither are detailed flow-charts of program logic. Both, however, are available according to the author.

8. Completeness:

This is a final thesis report. The model is validated in the sense that the program is operational and works in the expected manner.

9. Computer Implementation:

The computer program is written in FORTRAN (1824 cards). It was run on an IBM 7094 computer. Some degree of programming sophistication would be required in any attempt to improve and augment the model.

10. Modularity and Flexibility:

The program appears to be written in a very modular and flexible form. The use of many subroutines makes it possible to easily alter parts of the program or to add new features if so desired. The model can also be used as part of a larger package of programs.

11. Evaluation:

This model demonstrates the viability of fast simulation as an investigative tool for the terminal area. The outstanding quality of the present model is the amount of detail that it includes and the insight that it provides on the complexity of the task of simulating terminal area operations.

Although there is ample ground for improvement and augmentation, the model provides an excellent starting point for further work. It certainly merits serious study before any further work in undertaken.

1. Model: Simulation of operations in terminal area.

2. Identification of Related Report:

   Title: "A Fast-Time Simulation Model of Automated Terminal Area ATC Systems".

   Author: A.S. Jackson; R.V. Morse; J.P. Crocker

   Agency: Control Technology, Inc.

   Report#: AD 849550 (Contract # ARDS-394)

   Date: November, 1962.

3. Summary:

   This is a fast-time simulation model of an "automated" terminal area ATC system. Automation here implies guidance of the a/c through the terminal area by a computer with no controller intervention.

   The program described here is designed to handle a single aircraft at a time. The computer simulates the movement of a/c from the instant they enter the terminal area to the instant they touch down on the runway. No holding stacks are included since the model does not provide for traffic congestion procedures.

4. Model Type: Quantitative; fast simulation; some probabilistic variables (because of inclusion of an error function).

5. Features and Assumptions:

   The model disregards interactions among different a/c in the air. This, of course, results in great simplification of the model. Thus, although the program simulates the guidance aspects of a controller's work, it certainly omits the most complex part of his duties, namely aircraft sequencing and conflict detection and resolution.

   Aircraft heading, velocity, and position changes are simulated with considerable detail, including wind effects and navigational errors. Various statistics on the performance of the program can be collected.

6. Major Results:

The major result is the simulation program itself, which demonstrates the viability of fast-time simulation as a tool in the investigation of ATC problems. No mention of the model's final disposition is made.

7. Documentation:

A fairly detailed description of the model is provided. Flow charts (but no program listings) are presented, together with a list of the variables used and their meaning.

8. Completeness:

A final report. The program is validated in the sense that it is operational. However, because of its simplifying assumptions no realistic validation can be performed.

9. Computer Implementation:

The program is written in FORTRAN and was run on an IBM 7090. It is relatively simple by current standards.

10. Modularity and Flexibility:

The program is composed of an executive routine and of a number of subroutines. It could therefore be modified easily and augmented.

11. Evaluation:

At the time (1962), this program was of considerable significance in this area. Since then, however, more realistic programs have been written. Simpson's simulation, for instance, (see review C-1) incorporates all the attractive features of the present model, while including a number of additional and more realistic details.

1. Model : Simulation of a Terminal Area (Chicago)

2. Identification of Related Report :

   Title: A Methodology for Evaluating the Capacity of Air Traffic Control Systems.

   Author: R.S. Ratner (Project Leader), R.Burford and P.Reavelsy have prepared the model reviewed here.

   Agency: Stanford Research Institute

   Report#: SRI Project 8181

   Date: July 9,1970

   Other I.D.: Contract No. DOT-Fa 70 Wa-2142

3. Summary :

   We review here a simulation model of a "hypothetical Chicago terminal area". The description of this model is contained in Appendix D of the report identified above.

   The simulation model focuses attention on the portion of the terminal area which precedes the final approach sequencing area. It also does not simulate the holding stack areas or the runway operations.

   Three simulations are described, all hypothesizing the existence of a third airport ("Lake Airport") in the Chicago area (in addition to O'Hare and Midway airports). The first two simulations assume a set of altitude restrictions for aircraft flying various routes, while the third simulation disregards those restrictions.

   Various measures of system performance are obtained, including average number of aircraft in terminal area, terminal area capacity, terminal area delays and conflicts, etc.

   The simulation was performed by General Precision Systems Limited, England, subcontractors for SRI in this study.

4. Model Type : Quantitative, simulation. It is not clear whether probabilistic perturbations were included in the model and to what extent.

5. Features and Assumptions:

Given a demand pattern for the Chicago terminal area as provided by NAFEC, the model simulates an air-route configuration serving a hypothetical third airport in addition to the present two. Arriving and departing flights but no overflights are assumed.

The runways serve both arrivals and departures. It is not, at all, clear what the assumptions are concerning: service times at the runways; navigational accuracies in the system; distribution of errors, if any.

6. Major Results:

Estimates of workload, delays and capacity as well as identification of geographical points at which a high number of conflicts take place.

7. Documentation: The assumptions are not stated clearly and explicitly. There is a minimum use of flow charts and other aids that would assist in evaluating the validity of the model.

8. Completeness: The report reviewed was a draft of the first year-end report of a continuing study.

9. Computer Implementation : Very few details are provided on the mechanics of the computer programs used (no computer or language specifications). It is stated that the program can process "more than 5,000 aircraft through a 24 hours simulated day in some 5 minutes of actual computer time". GPS has developed these in-house simulation programs and markets their usage to customers in Europe and the USA.

10. Modularity and Flexibility: It is stated that several options are available in the model so that it can simulate a variety of situations and procedures. No mention of possible interfacing or compatibility of this simulation program with other programs is made.

11. Evaluation:

The description of this simulation model, as is often the case, is inadequate and makes it difficult to pass judgement on the merits of the method.

The basic assumptions with regard to the model are not stated explicitly. Particularly disconcerting is the fact that there is no discussion of runway usage assumptions. As the runway/final approach happen to be the main bottleneck of the system, it would seem that performance in a terminal area depends critically on runway occupancy time, priority rules for runway usage, etc. Yet, these items are never mentioned.

The general impression seems to be that this simulation model can quickly produce results that may identify possible trouble spots in a terminal area or indicate a fundamental inadequacy of one element of the terminal area system. For example, one of the simulation runs indicated that the available runways were inadequate for the given demand level. Thus, this model can be useful in eliminating some poor alternatives among a number of possible terminal area designs. It is questionable, however, whether the model is refined enough to serve for any additional purposes.

1. Model: Real Time Simulation of a Terminal Area (New York)

2. Identification of Related Report:

   Title: New York Air Traffic Capacity Study
   Author: Howard F. Slattery
   Agency: FAA (NAFEC, Atlantic City, N.J.)
   Report#: NA-70-15
   Date: February 1970
   Other I.D.: FAA Project No. 154-004-02X

3. Summary:

A simulation study to determine the operational benefits resulting from a plan designed to increase airspace and airport capacity in the New York Area was conducted at the National Aviation Facilities Experimental Center, Atlantic City, New Jersey

The study included terminal area operations and two different segments of the en route environment. The operational plan submitted for evaluation used area-navigation as the prime method of aircraft guidance, assumed that additional runways were available at Newark and Kennedy Airports, and that the aircraft would be metered into the terminal area.

It was concluded that features of the operational plan increased the operation rate of the entire New York Terminal Area by more than 50 percent, the departure operation rate of the en route area by 140 percent, and the arrival operation rate of the en route area by 97 percent. It was further concluded that the increased terminal capacity was due more to the additional runways at Newark and Kennedy than to the terminal track system associated with the area-navigation. However, the area-navigation and track system concept contributed greatly to the increase in operations rates within the en route area.

4. Model Type: Real time simulation at NAFEC facilities (Atlantic City, N.J.).

5. Features and Assumptions:

The report assumes addition of runways at Newark and Kennedy Airports and adoption of area navigation. Given a detailed description of the New York terminal area, statistics were obtained related to the movement of traffic in the enroute departure segment, the en route arrival segment, and the terminal segment.

6. Major Results:

Estimates of future capacity of New York terminal area. Increased capacity was found to be due more to the additional runways than to the terminal track system associated with area navigation.

7. Documentation: Complete description of the simulation.

8. Completeness: Final Report. The recommendations for the addition of runways at JFK airport were not implemented, nor does it seem likely that they will be implemented in the foreseeable future.

9. Computer Implementation:

This is a real time simulation. Preparing a fast simulation of the same scope and realism would constitute a project of greater magnitude.

10. Modularity and Flexibility:

The real time simulation, as designed is flexible in that it provides several options regarding the number and type of experiments conducted.

11. Evaluation:

The report describes a typical real time simulation similar to several others that have been conducted at the NAFEC facilities. These simulations encompass a considerable degree of realism and produce sensible results. On the other hand, it appears that performing such simulations requires considerable amounts of money, time, and manpower. In addition, because of the inherent slowness of real time simulations, they are not well suited to the performance of sensitivity analyses and to the investigation of large numbers of options.

The description of this simulation should be studied carefully because it provides the reader with an understanding of the type and extent of the simulation capabilities presently available at Atlantic City.

1. Model: Simulation of Operations at an Airport

2. Identification of Related Report :

   Title: "DELCAP: A Simulation model for estimating terminal-area throughputs and delays."

   Author: E.Short; W. Steele; J. Gilsinn; D. Klauan

   Agency: National Bureau of Standards

   Report#: A draft copy was reviewed

   Date: January 1971

3. Summary:

The report describes a simulation model for an airport. The model is general enough to include multi-runway operations and simulates both landings and take-offs.

Abstract

This report documents a model designed to estimate airport throughputs and aircraft delays, taking into account their dependence on (1) the traffic level and mix of user types (2) the airport configuration, and (3) the separation rules in force. The model is implemented in two parts, a preprocessor to facilitate data entry by providing standard data input which a user may elect instead of providing his own, and an event-oriented simulation model. The report includes a discussion of the elements in the airport system which are modelled, a description of the simulation model's logic, and a set of sample outputs. Listings of the model programs, and a users' guide to their operation, appear as appendices. The report concludes with suggestions for next steps in this development effort, including validity and sensitivity analyses, model modification, and data collection.

4. Model Type: Simulation ; quantitative; some variables are probabilistic and some deterministic

5. Features and Assumptions:

The model uses some of the concepts developed in a previous N.B.S. document entitled "Analysis of a Capacity Concept for Runway and Final-Approach Path Airspace" (see Cat. B for evaluation) However, the scope of the present study also includes departures, multiple runway operations and delay statistics. Several assumptions are made about assignment of priorities for runway use. These assumptions are intended to reflect the currently prevailing procedures at major airports.

Other assumptions include: (i) IFR traffic only; (ii) no wind effects; (iii) perfect delivery of landing aircraft at the glide-path; (iv) deterministic approach speeds and runway occupancies for each aircraft type; (v) constant user mix and operational procedures throughout a simulation run; and (vi) no effects from airport surface traffic movements on runway throughput rates. Of the above, (ii) and (iii) should be the assumptions that most seriously detract from the value of this simulation model in its present form.

6. Major Results:

The major result of the report is, of course, the simulation program itself. The model in its present form is a first (but complete) cut at simulating runway operations for any given set of runway configurations and traffic control procedures.

7. Documentation:

Very detailed and explicit description of the model. Complete listing of the computer program. Examples of inputs and outputs are provided as well as instructions for using the program.

8. Completeness:

The present report completes the first phase of development of this simulation model. No information is provided on whether a second phase is forthcoming. The model is validated in the sense that the computer program is operational and behaving in the expected manner.

9. Computer Implementation:

The computer program is written in FORTRAN V and SIMSCRIPT(a computer language particularly suited for simulations). It was run on a UNIVAC 1108 computer. Some modifications may be needed for conversion to other computers. In general, modifying and augmenting the program would require some degree of sophistication in computer programming.

10. Modularity and Flexibility:

The model is specifically designed for use under a variety of conditions and assumptions. It is, therefore, both modular and flexible. It can very easily be included in a larger system of some sort.

11. Evaluation:

This is an excellent first cut at an airport simulation model. The detailed description of the model and the explicit statement of the assumptions provides an opportunity to both understand the work and to check on its validity and reasonableness.

Some individual assumptions in the model are debatable as noted above under "features and assumptions". Also, there is ample room for augmentation and improvement of the model, as the authors themselves note in Chapter 5 of the report. However, the basic principles of the program seem to be sound and, even in its present form, the model can lend considerable insights on the operation of an airport.

In conclusion, this model must be thoroughly studied before any future work is undertaken.

1. Model: Terminal Area Models

2. Identification of Related Report:

   Title: An Investigation of the Expected Magnitude of Control Errors in the TASC I System Transition Area.

   Author: Harold I. Ottoson

   Agency: FAA

   Report#: 5

   Contract: BRD-112

   Date: June 1960

3. Summary:

In this write-up we review a model for determining the expected magnitude of control errors when the purpose of aircraft control in the transition area is to deliver aircraft on schedule at the inner fixes. The control instructions to achieve this goal are of two kinds: 1) If an aircraft is ahead of schedule at an updating line (there are three such lines between the outer fix and the inner fix) a delaying dog leg type vector instruction is derived, and 2) if an aircraft is behind schedule at an updating line, a speed-up instruction is computed.

4. Model Type: Quantitative, probabilistic, analytical.

5. Features and Assumptions:

   Computer assumes ideal system (ideal control, piloting, zero wind, etc). The dog leg control instruction assumes that the speed remains constant, and that the initial angle of the dog leg is constant. The speed control instruction assumes a step change in velocity or infinite acceleration capability, the schedule error determined by the computer at the update is the maximum that the aircraft can make in the distance S (the distance from the update line to the inner fix or the next update line), and that acceleration a is constant.

6. Major Results:

The results are given in graphs which indicate that the accuracy of a vector (dog leg) control instruction, assuming initial position errors of ± 0.5 mile, speed profile error of ± 10 knots, and heading errors of ± 2°, cannot be expected to be much better than approximately one minute; and that speed control accuracy assuming the same input values cannot be expected to be better than 30 seconds.

7. Documentation: Complete

8. Completeness: A final report.

9. Computer Implementation:

Computation was performed by the IBM-709 computer for a range of the maximum expected values of the individual components of the error. No other reference is given to computer implementation.

10. Modularity and Flexibility:

There are little possibilities of extending the model to include additional considerations, or to include the model in a larger system.

11. Evaluation:

This model states the importance that control instruments (radar) may have in the determination of the capacity of the landing system of an airport. It should be emphasized that the current system produces a time error at the inner gate that is much smaller than the one predicted by the model. The reason is that the model assumptions are too strong, making the model too inflexible and unrealistic.

1. Model: Scheduling Model for Terminal Air Traffic

2. Identification of Related Report:
   Title: The Terminal Air Traffic Scheduling Model
   Author: G.W. Ingram
   Agency: System Development Corporation
   Report#: TM-639/003/00
   Date: September, 1963.

3. Summary:

   "This paper is a report on the development of a terminal air traffic control scheduling model. The first part is historical, covering the steps in the development of the model. The second part documents the present model. In the third part, a suggested study is introduced in which scheduled traffic flow would be examined while it is being influenced by factors such as distribution of input, maneuverability of input, and characteristics of the space in which the scheduling is being performed. Presently, there are no plans to initiate this study, and further development of the scheduling model is contingent on the degree to which the model can be generalized."

4. Model Type: Quantitative; Probabilistic; Analytical.

5. Features and Assumptions:

   The northwest quadrant of the San Francisco - Oakland area is chosen as the terminal area and paths and nodes in this area are designated. Twelve different aircraft types are permitted. The model receives intention plans from the aircraft using path selection, speed control, and proximity checks. Speed control is capable of slowing aircraft to 85% of their cruising speed.

6. Major Results:

   The paper describes a terminal area traffic scheduling model and offers suggestions for future investigations and improvements in this field.

7. Documentation: Incomplete - The outputs of a few sample computer runs of the model are included in the appendix.

8. Completeness: A plan to study the effectiveness of the model is outlined. Future work is suggested if the model can be easily generalized.

9. Computer Implementation:

It appears that a general model would be difficult to implement.

10. Flexibility and Modularity:

If different priorities were decided upon, this model should be able to adapt fairly easily.

11. Evaluation:

The best feature of this report is the historical approach in which the development of the model is discussed, along with the problems and alterations along the way. Whether the model is sufficiently general is still open to question, especially for high traffic density areas. This report could be read to gain insight on the problem of designing a semi-automated control system.

1. Model: Standard Holding Pattern

2. Identification of Related Report:

   Title: An Analytical Investigation of Air Traffic Operations in the Terminal Area.

   Author: Robert W. Simpson

   Agency: M.I.T.

   Report#: None (Ph.D. Thesis)

   Date: August 1964.

3. Summary:

   This review is concerned with a model of the holding stack configuration which is internationally accepted as standard. The main concern is to find the capacity of the holding stack and to study the different alternatives for increasing it and making the process more deterministic.

Abstract

During busy periods of airport operation, the holding stacks are likely to be in use, and since their output feeds directly into the regulator, a significant improvement in busy period terminal area traffic control can result if the variance of stack output can be minimized. It is also important to know capacity restrictions, and to be able to analyze the effects of controller variables, different pattern geometries, operating policies, etc., on holding stack output. The problem under study here is that of getting an aircraft out of its pattern and through the fix point in the preferred exit direction. The vertical process, laddering, is ignored. The mean and variance of exit times, and time separations between exit aircraft can then be computed under certain assumptions of ideal operation.

4. Model Type: Quantitative, Probabilistic, Analytic.

5. Features and Assumptions:

This model assumes ideal piloting and zero wind, and as the holding pattern is defined in "time space", the effect of different aircraft holding speeds is eliminated. It is also assumed that aircraft are always available and uniformly distributed around the holding stack. With these assumptions the average exit interval, its standard deviation and the capacity are graphically obtained.

6. Major Results:

The average exit interval and its standard deviation are plotted versus the warning time (a specified interval delaying aircraft exit until some future time). Also, capacity is plotted versus warning time for different aircraft separation times (a guaranteed time interval between successive exits to ensure safe exit operation) and different control delay time.

7. Documentation:

Lacks written analytical equations, all the computations being graphical.

8. Completeness: Final Report

9. Computer Implementation:

It would require analytical expressions that have not been derived. Once this is done, computer implementation must be simple.

10. Modularity and Flexibility:

This model can be included in a larger system and it can be extended if more variables (wind, vertical action, etc.) are considered.

11. Evaluation:

This is a good first model that permits a quick calculation of the holding stack ouput capacity, the average exit interval and its standard deviation. These results are of main importance to the estimation of the capacity of the whole landing system, giving and idea of the amount of output provided by the holding stack compared with the output provided by the following stages of the landing process. A weakness of the model is that all the calculations are done graphically and no analytical equations are shown, presenting a disadvantage for possible computer implementation.

1. Model: Semi-Orbit Holding Pattern

2. Identification of Related Report:

Title:	An Analytical Investigation of Air Traffic Operations in the Terminal Area.
Author:	Robert W. Simpson
Agency:	M.I.T.
Report#:	None (Ph.D. Thesis)
Date:	August 1964.

3. Summary:

This review is concerned with the model of the holding stack developed by the author that shows how the capacity of the holding stack can be improved by simply changing the geometry of the pattern. The semi-orbit pattern is not used in reality, although it is as simple as the six-minute pattern that is reviewed in a separate write up.

Abstract

Since the reasons for adopting the racetrack holding patterns have disappeared, it is interesting to consider newer holding patterns that make use of improved navigation aids, offer simpler piloting procedures, and easier automation of flying the pattern, and as well promise greater capacity and regularity of output flows. The simplest holding pattern is a circle of steady orbit about the holding point. That can be used for extended periods of holding. The problem of leaving the pattern on a preferred exit direction dictates that at lower holding altitudes, a semi-orbital pattern be used.

4. Model Type: Quantitative; Probabilistic; Analytical.

5. Features and Assumptions:

As with the six-minute pattern, this model assumes ideal piloting and zero wind, and always available aircraft which are uniformly distributed around the holding stack. The pattern is defined in time-space.

6. Major Results:

Graphs of the capacity and of the standard deviation of exit intervals as a function of warning time.

7. Documentation: Lacks written analytical equations, all time computation being graphical.

8. Completeness: Final Report.

9. Computer Implementation:

Simple once analytical expressions are obtained.

10. Modularity and Flexibility:

This model can be included as a submodel of the whole landing system, and it can be extended if more variables (wind, vertical action, etc.) are considered.

11. Evalution:

This model should be studied as it is an attempt to increase the capacity of the holding stack without having to change any concept of the landing process or having to use new instruments. It is better than the six-minute pattern not because the capacity is higher, but because the standard deviation of the exit interval is much smaller. This is achieved by making a better use of airspace.

1. Model : Flow Control at a Terminal Area

2. Identification of Related Report:

Title: Flow Control - An Investigation of a Technique for Predicting Demand and Service at the Terminal Facility.

Author: Gordon D. Jolitz

Agency: National Aviation Facilities Experimental Center

Report#: NA-68-20

Date: August, 1968.

Other I.D.: RD-68-44; AD 673667

3. Summary:

ABSTRACT

The concept of the flow control function as a part of the Air Traffic Control (ATC) system includes a requirement for information about the volume of air traffic demand on the ATC system relative to the system's capacity for servicing such a demand. Furthermore, the information is needed sufficiently far in future time to permit action to be taken when a serious imbalance is predicted.

The demand prediction process described in this report was based on two related hypotheses: a) air traffic demand on an airport is repetitive in nature such that historical operations data would be useful as a prediction; and b) operations information known to the Air Traffic Control (ATC) system would be a useful predictor. A computer program was developed which permitted joint use of the two predictors and, using sample data from a test case (Washington National) airport, the prediction model was evaluated. A companion program which was designed to provide service predictions took into account such environmental factors as weather and runway configuration.

The criterion against which the model's predictions were tested was a count of actual operations. It was concluded that demand predictions were not highly correlated with the criterion and that errors in prediction appeared to be normally distributed and random with time. It was recommended that future efforts consider other predictors and/or prediction processes than those used in this experiment.

4. Model Type : Quantitative, probabilistic, analytical, heuristic.

5. Features and Assumptions:

   The model is based upon two fundamental hypotheses. "First, it was hypothesized that there was a repetitive characteristic of traffic which flows into and out of an aiport such that historical operations rate data would be useful as a predictor of future demands on the facility. The second hypothesis was that a stable relationship existed between the amount of flight plan information known to the ATC system for some future time period and the amount of traffic activity which would ultimately place demand on the airport."

6. Major Results : The results essentially disprove the two hypotheses assumed.

7. Documentation : Incomplete - Computer program not included.

8. Completeness : Recommendations are forwarded that a flow-control subsystem still be developed, using other approaches.

9. Computer Implementation : Simple. The programs used were written in FORTRAN for the IBM 7090. No mention was made of running time.

10. Flexibility and Modularity :

    Since the model was disproved, it should not be included in any wider model.

11. Evaluation : The report is well written but unimportant due to the fact that its hypotheses have been disproved. Knowledge of this factd should be sufficient and the report need not be read.

1. Model: Delays at Near-Saturation Levels

2. Identification of Related Report:

   Title: A Model of Long Delays at Busy Airports

   Author: Alan Carlin and Rolla Edward Park

   Agency: The RAND Corporation

   Report #: P-4126(AD 691 860; Sponsor: Port of New York Authority)

   Date: August 1969

3. Summary :

   This report describes an effort to model long delays at airports when the arrival rate is close to or greater than the service rate.

   Author's Description

   The primary purpose is to provide a tool to assist in evaluating the benefits, in terms of reduced delay, of any policy to limit traffic. Along the way, an improved method of estimating delay patterns is outlined, and traffic and delay estimates for Kennedy arrivals are presented. As an illustration, the model is fitted for Kennedy arrivals. Although this application of the model is primitive in some respects, the results are very encouraging as to the potential usefulness of the model.

4. Model Type:

   The authors describe the tool as a "simple deterministic queuing model".

5. Features and Assumptions :

   The report defines and assumes a logical arrival rate and a valid acceptance rate and hypothesizes a delay forming relationship for a large arrival rate. Three weaknesses of this methodology are recognized: (1) Actual arrival rates suffer major intra-hourly variations and are not precisely portrayed by the assumed smooth curves. (2) Model differentiation between arrivals and departures and various combinations is yet unresolved. (3) The model holds strictly only for individual days.

6. Major Results:

The model proved to be a useful and accurate aid for evaluating traffic limiting policies at Kennedy Airport. Three such limitations were tested: (1) The general aviation component was reduced by one half with the air carrier component remaining unchanged. (2) The general aviation component was completely removed. (3) The general aviation component was halved and carrier operations were reduced during assumed periods of bad weather. The results are given in terms of peak average delays and total yearly delays. Also an attempt is made to express the improvements in monetary terms.

7. Documentation:

The report is very explicit with complete definitions of parameters and variables, logic outline, and a computer program for the schedule evaluation. The inputs for arrival rates are derived from air carrier schedules and observations of general aviation operations, and the outputs are registered as delay in minutes with some monetary factors applied.

8. Completeness:

The report gives no indication of future work for the model, but it is very complete with a validation based on data from Kennedy Airport operations for one year beginning in April of 1967.

9. Computer Implementation :

The program was prepared for JOSS, RAND's remote control, time sharing computer system so other implementation should only be a matter of translation.

10. Modularity and Flexibility:

The elementary form of the model as presented in the report is not very modular, but is quite flexible and the authors believe that extensions are possible.

11. Evaluation :

This is an excellent example of a complete modeling effort and much can be gained from a study of its results and methodology. It even contains its own accurate evaluation: "This application of the long delay model to Kennedy arrivals has been rough in several aspects: one hour periods neglect intra-hourly fluctuations in demand, some account should be taken of interdependence between arrivals and departures, and further disaggregation would surely improve the model. Nevertheless the model fits delays to Kennedy arrivals quite well. Even in its present primitive form, it is probably the best available estimator of the effects on delay patterns of changes in arrival patterns at Kennedy. In a more refined version, it could be a valuable tool for evaluating alternative policies to limit congestion at other busy airports as well".

1. Model: Analytic Study of Air Traffic in a Terminal Area (New York)

2. Identification of Related Report:

   Title: Analytic Study of Air Traffic Capacity in the New York Metropolitan Area

   Author: W. Faison, M. Meisner, E. VanDuyne.

   Agency: FAA Systems Research & Development Service

   Report: RD-70-4

   Date: February 1970

   Other I.D.: Project No. 154-004-01R

3. Summary :

   The study examines several alternatives for increasing capacity in the New York metropolitan area. The effects of adding runways at Kennedy International and Newark, the use of standardized instrument arrival and departure procedures, the use of a revised route structure based on area navigation capability, the use of automated control aids and regulating traffic are estimated. The models used, apparently are those first developed by AIL for "Airport Capacity Criteria".

4. Model Type: Quantitative, probabilistic; analytical.

5. Features and Assumptions :

   Assumes addition of runways at JFK and Newark airports, revised route structures, and automated control aids. Attempts to estimate effect of these changes (either individually or combined) on future capacity of New York Metropolitan Area.

6. Major Results :

   Estimates of future capacity of major New York airports resulting from various construction and procedure modification programs. The results tended to confirm the estimates of the simulation study.

7. Documentation: Rather complete. Assumptions are not always clear.

8. Completeness: Final report.

9. Computer Implementation: No computer implementation envisioned.

10. Modularity and Flexibility: This is a self-contained study.

11. Evaluation:

This report is the best example of an application of existing analytical methodology to problems of a specific geographic area. That methodology was developed by AIL for the FAA and is revived in this catalog (see Slattery, " New York Air Traffic Capacity Study"). However, the recommendations have not been implemented, and it does not seem likely that the proposed expansion of JFK airport will take place within the near future.

Regardless of this outcome the report is particularly interesting because it considers not only the physical airport capacity, but also the possible limitations that may result from airspace constraints and control sector overloads. Although one may disagree with the basic validity of some of the models and tools which the study uses, the structure of the report can serve as a model for future studies of this type.

1. Model : Terminal and Transition Area Capacity

2. Identification of Related Report :

   Title: Techniques Useful in the Assessment of Terminal Area Design and Capacity.

   Author: M.A. Warskow

   Agency: Airborne Instruments Laboratory

   Report#: No Number (Presented at the 17th Technical Conference International Air Transport Association).

   Date: October, 1967.

3. Summary :

ABSTRACT

Techniques of analysis have been developed which are useful in terminal area study and assessment. A quantitative evaluation can be made of the effect of air route changes, the effect of airport expansion in numbers of runways or number of airports, the effect on traffic flow of inter-airport conflict and the capacity of terminal area airport systems. The techniques are described so as to include analyses of transition airspace in the terminal area approach and departure paths to and from all IFR airports and airport operations. Applications of the techniques is illustrated with examples.

4. Model Type : Quantitative, probabilistic, analytical.

5. Features and Assumptions :

   Transition airspace is defined as that airspace within an area that is large enough to incorporate aircraft climbout and descent paths to and from all the major airports in a terminal area. Complexity ratings are defined on the transition airspace such that areas which require greater control effort have greater complexity ratings. Capacity is defined as a function of average aircraft delay.

6. Major Results :

Examples of how complexity ratings are compiled in the present and also the future are presented, giving insight to a terminal area's traffic problems. Computations for practical hourly capacity, practical annual capacity and annual delay are also presented for different stages of airport development.

7. Documentation : Incomplete. Computer programs are mentioned for computing the complexity ratings and the different capacities, however the language or machine used was not specified.

8. Completeness : The techniques described in this paper are to be expanded, updated and applied to various situations.

9. Computer Implementation : Simple.

10. Flexibility and Modularity :

These techniques and approaches can be fairly easily adapted to a number of situations.

11. Evaluation:

This paper was presented at the 17th Technical Conference of the International Air Transport Association and thus was not meant to be an in depth report. Rather the paper summarizes the work done by the Airborne Instruments Laboratory AIL) in the air traffic control field. Although AIL's approach of defining capacity as a function of delay is currently open to question, this paper offers a good review to AIL's approach to air traffic control.

1. Model: Final Approach and Runway Landing Capacity/ Airport Surface (See A-5 for complete evaluation)

2. Identification of Related Report:

Title: A Simulation of the Airside Traffic at an Airport

Author: Stephan Hall

Agency: United Aircraft Research Laboratories

Report #: J-170648-1

Date: July 28, 1970

1. Model: Runway Capacity

2. Identification of Related Report:

Title: Capacity of Airport Systems in Metropolitan Areas - Summary: Methodology of Analysis; and Validation.

Author: M.A. Warskow and I.S. Wisepart

Agency: Airborne Instruments Laboratory

Report#: AIL#s 1400-3, 1400-4, 1400-5.

Date: January, 1964.

3. Summary:

This report has three parts. The first part, Summary, summarizes the work completed. The second part, Methodology of Analysis, presents a synopsis of the considerations involved in determining the practical annual capacities (PANCAP) of each airport in a metropolitan area. The PANCAP is determined from the practical hourly capacity (PHOCAP) which is defined in AIL's Airport Capacity Handbook . The third part, Validation, compiles statistical data from airports in four metropolitan areas and computes the PANCAPs. The validation intends to verify the application of the technique.

Abstract

Since airports in metropolitan areas complement and interact with each other, they must be planned and operated as part of a system of airports. Furthermore, as air traffic continues to increase, more airports in metropolitan areas approach and reach capacity operation. Therefore, it is desirable to plan each airport in a metropolitan area as part of a system of airports in order to obtain the most efficient traffic flow as well as the most efficient use of facilities.

The operational factors involved in planning a system of airports in metropolitan areas are analyzed and used to determine the causes of congestion. Data obtained from previous studies is used to understand and demonstrate the operational factors and congestion. Airport congestion is defined in quantitative form for an individual airport and a system of airports.

A methodology is presented that permits the many factors affecting the operation of an airport in a metropolitan system area to be evaluated quantitatively. The annual demand at which these airports will reach their practical annual capacity is determined by considering the effects of airport interactions and by determining quantitatively when congestion will occur at one airport and in the airport system.

4. Model Type: Quantitative; Probabilistic; Analytical.

5. Features and Assumptions:

PHOCAP equals the total hourly movement that can be sustained over a 2-hour period by a runway configuration at which the average delay is at a specified level.

The practical annual capacity (PANCAP) is determined by three factors:

1) Percent of hours during the year when the hourly demand exceeds the practical hourly capacity. (The practical hourly capacity is defined to be the number of aircraft that can be serviced in an hour with an average delay of 4 minutes.)
2) Percent of annual operations occurring during the overloaded hours.
3) Average delay to overloaded operations.

6. Major Results:

This report presents the methodology of analysis necessary to determine the capacity of airport systems in metropolitan areas as well as a validation of this technique.

7. Documentation:

Complete - No computer program to calculate the PANCAPs are included in the Validation.

8. Completeness:

"The validation presented in this report has permitted the selection of reasonable levels of delay to determine PANCAP. However, these levels of delay should be re-evaluated as more precise annual statistics become available and as experience is gained in the use of this technique".

9. <u>Computer Implementation</u>:

Simple. Although no program was given, the computations are straight forward.

10. <u>Flexibility and Modularity</u>:

Easily adaptable to various airport configurations.

11. <u>Evaluation</u>:

The determination of a practical annual capacity (PANCAP) for airports in a metropolitan area appears to be a good first order approximation to evaluate the needs and capabilities of that area. Beyond that, however, the evaluation of the PANCAP does not appear to be of great importance. The PANCAP has the underlying concept of capacity as being defined as a function of delay, and this assumption is currently open to question.

1. Model : Terminal Area Landing Simulation

2. Identification of Related Report :

   Title: Functional Description of Basic Terminal Approach Simulation Model

   Author: J.A.Keenan, A.E.Barnsby

   Agency: MITRE Corporation, Washington, D.C.

   Report #: MITRE Technical Report MTR 4071

   Date: March 21, 1969

3. Summary : This report details an initial effort of creating a basic fast-time terminal area simulation. It also contains a brief description of a separate traffic generator which models merging streams of aircraft and is suitable for other independent simulations.(See B-17).

   Author's Abstract

   "This paper functionally describes a basic terminal approach simulation model and a separable traffic generator. The description is given both from a general system point of view and from a computer programming point of view."

4. Model Type : Qualitative; simulation.

5. Features and Assumptions : The area modeled is within 30 miles of the center of an airport. The initial effort involved only a single runway used exclusively for IFR/ILS arrivals and prohibited weather or other environmental factor dynamics. Only two aircraft types were considered: standard wing-powered and tail-powered passenger carriers.

6. Major Results : The report gives the intended results as: gathering of rare data at reasonable rates; elimination of undisciplined human actions; and allowance for flexibility of objectives for testing. These general results are due to the elementary nature of the model.

7. Documentation : The report includes definitions of parameters and variables, and it contains numerous informative flow charts, but no equations. The model program is not listed, either.

8. Completeness : According to the report the modeling effort is continuing and it gives the proposed revisions, extensions, and validation requirements.

9. Computer Implementation : The model was developed specifically for the 7094 System in GPSS III language as requested by NAFEC; the traffic generator is written in Fortran IV. The initial model would be simple to program, but the current developments may be much more sophisticated.

10. Modularity and Flexibility : One prime objective of the effort is modularity and flexibility, and the authors point out their intentions to expand the model to include multiple aircraft types and navigation aids, VFR operations, and departures. The sole purpose of the traffic generator is to provide a simulation useful for many other ATC modeling efforts.

11. Evaluation : The primary value of this report and its model is its basic approach to the problem. For a first effort this model could easily serve as an example; for an advanced study this basic model would be useless, but its successors may well be worth consideration. (See B-17).

1. Model : Airport Queuing Simulation

2. Identification of Related Report :

   Title: Simulation by Incremental Stochastic Transition Matrices.

   Author: John E. Hosford

   Report#: MDC 69-026

   Date: November, 1969

   Other I.D.: Paper C-MP 1.5 at 36th National Meeting of ORSA.

3. Summary :

A simulation technique is developed using the basic principles of Markov processes whereby the complete distributions of the landing queue, the take-off queue, and the queue at the gates is calculated. An example is included which simulates runway and gate operations for a STOL airport.

Abstract

Simulation by Incremental Stochastic Transition Matrices (SISTM) is a direct probabilistic simulation technique applicable to most queueing systems. SISTM uses a state vector giving the probability, for each queue, that the queue has X units waiting for service (X=0,1,2,3,...). This state vector is updated every time increment by multiplying it by a transistion matrix giving the probability that the queue length changes for X to X' units. SISTM can change the arrival and service distribution every time increment, can use any discrete service time distribution, and can be used to evaluate systems which have sequential and parallel queues.

4. Model Type :

Quantitative; probabilistic; simulation. The simulation for a STOL airport model is described in detail.

5. Features and Assumptions :

Minimum time separation requirements are considered between consecutive operations. The requirement of the runway being occupied by one plane at a time is adhered to. However no mention is made of minimum separation standards in the air, nor of speed of landing, or error variability with weather and equipment.

The state description of the system includes the length of every queue, and may include the probability that each server (here gate) is occupied. For every queue a maximum queue length is selected such that the probability of exceeding that value is very small.

6. Major Results :

The complete distribution of each queue in the model is obtained. The output from SISTM is the status of the system being simulated for every time period throughout the day.

7. Documentation : Complete. Coding used in the example simulation is explained in detail.

8. Completeness : The program explained in the report is not a general purpose SISTM program, but it deals specifically with a STOL airport simulation. It is suggested that suitable SISTM programs can be developed for general purposes.

9. Computer Implementation Requirements :

Simple. For the example given programming time was under 100 hours, and it is written in Fortran IV. Runs were made on an IBM System 360, Model 65/15.4.5 min. machine time were required to simulate 17 hours of STOL-port operation.

10. Flexibility and Modularity :

Model can be made more realistic by including distance separations in the air, and a general purpose SISTM may be developed with considerable effort.

11. Evaluation :

SISTM is a new simulation technique to perform a probabilistic simulation of queueing problems. It differs from Monte Carlo) simulation, which requires a large number of runs. SISTM uses a Markov Process approach, and a single run gives the desired results. With this technique it is possible to vary the rate of arrivals, have several service funtions in series or parallel and change the service time distribution with time of day.

SISTM is generally more difficult to prepare than a Monte Carlo simulation, since it is necessary to define mathematically the parameters which determine the probability of changing state. The length of the time interval used for updating the transition probability matrix influences the difficulty of preparing the run and the computer time is directly proportional to the number of time periods.