AIR TRAFFIC CONTROL SCHEME THROUGH SIMULATION

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ABSTRACT

The objective of this study is to develop a simulation model to effectively assist in planning air traffic control operations in the terminal area. The analysis applies unique concepts to the air terminal system, employing a discrete events simulation philosophy through the proven simulation language known as GASP.

In pursuing this objective, the study includes pertinent factors associated with actual air traffic operations such as multiple runway dependency, landings and take-offs, aircraft flight characteristics, interaction between approaches, traffic control standards, wave-offs, arrival and departure structures, and so forth. A systems approach has been taken in designing the model so that the components of the system and their complex interactions are represented realistically. The validation of the model indicates that the discrete event modeling philosophy can adequately simulate air terminal operations.

The model is capable of providing solutions for a variety of air terminal operations. An attempt is made to indicate the applicability of the model in such system analyses as runway assignment policy, lending sequencing policy, runway capacity, sensitivity studies and economic analysis.

I. INTRODUCTION

The demand for air transportation is increasing faster than the improvments and modifications being made to keep the air traffic control (ATC) system properly responsive. This traffic control represents a very complex system in which the system components interact with each other in complex ways. No simple description of the behavior of the system is available from which deductions can be drawn covering the effects of changes in the system parameters in the system performance. To evaluate the effect of new system concepts on the complex ATC system, the most economical means is that of computer simulation. The simulation of the ATC system in the terminal area using digital computers has been used to an increasing extent in recent years.

This research was performed by the Civil Engineering Department of Virginia Polytechnic Institute and State University as part of the National Science Foundation Grant No. GK-30325.

This paper describes a large scale simulation model of an airport terminal area suitable for analysis of the stochastic air traffic control problem introduced by the random inter-arrival time and the stochastic nature of aircraft flight time in the terminal area. Since the discrete event simulation concept offers the capability of evaluating the air terminal system in a speedy and economic fashion, this research employs the essence of this philosophy but greatly extends the number of system components included and the ease of applying the model to an actual situation. The model considers the effects of all pertinent facets of the actual system, yet is flexible enough to be easily applied to any particular airport terminal area.

The specific objectives of this study include the following:

1. Analysis including runway utilization, delay and safety under various operating schemes.
2. Comparison of the merits of various landing sequencing and runway assignment procedures.
3. Evaluation through sensitivity studies of such factors as reduced separation distance and imporved control over system errors.

To best indicate the applicability of a simulation model for studying the air traffic control problem, it appears to be very important to provide an analysis from a total system viewpoint. This system approach enables the model to determine the overall effect on the congestion delay, safety and runway utilization as a consequence of any proposed system imporvements. In this system approach, the system is viewed as including the approach and tower control of aircraft, the performance of aircraft themselves, the ATC procedures, various navigational and control equipment, etc. The modeling philosophy of this study is that the aircraft are not treated dynamically by calculating positions and velocities each step through the system, as was done by most previous studies. Rather, aircraft are "flown" through the system by indexing them through three nodes--the holding stack, a point on final approach and touchdown. The system operates on a time basis causing the arrival of an aircraft at a node only at the proper time, and assuring proper aircraft separation throughout the system.

II. MODEL FORMULATION

This section presents the Air Terminal System Simulation (ATSS) model developed by this study. A systems approach has been taken in designing the model so that the many components of an actual system are represented realistically. Primary emphasis was placed on modeling interactions among these components, and from these interactions greater insight into the operations of the entire system will result.

The main goal in constructing the ATSS model was complete versatility in describing the system. That is, the model was designed to be general enough to simulate the terminal area operation of any airport regardless of its size, location or geometric constraints. The model possesses a number of capabilities and characteristics. These are:

1. Flexibility to simulate multiple runways,
2. Capability of studying all types of aircraft, including their individual landing and approach characteristics,
3. Capability of generating random arrival into the system,
4. Capability of using aircraft sequencing policies other than first-come-first-served sequencing.

A fast-time simulation model for the analysis of air terminal systems is developed. The discrete events philosophy is used for the simulation model. The GASP simulation language is used as the executive controller of the simulation. The GASP simulation enables efficient modeling of a large scale system with relatively straightforward logic. The entire model, including the GASP is coded in FORTRAN. With such a design, the use of the ATSS model can be learned quickly, and the model can be used on any computer with FORTRAN compiler.

The ATSS model provides a modular format which allows changes and additions to be made easily. The operations of the ATC are represented by a set of subroutines. GASP maintains overall control of all non-GASP subroutines. It also collects desired statistics, generates output reports and provides air efficient dynamic storage of operating variables.

SYSTEM IN SIMULATION

The system as perceived by the simulation model is an abstraction of the real system. When an aircraft reaches the destination terminal, it is "handed off" to the approach control. If the arrival rate exceeds the terminal acceptance rates, aircraft are delayed in queues or holding stacks. The model will simulate holding stacks for these aircraft arrivals in the terminal area. If the holding stack is empty, the arrival aircraft would proceed immediately toward the runway and be cleared into the approach sector.

The approach sectors, each of which is controlled by a single person, are representative of the ATC function. The simulation model includes a limit on the number of aircraft allowed in each of these sectors which represents the capability of the controller. When a sector reaches its limit, additional arrivals are held in the holding stacks. Departure from the holding stacks occurs when an aircraft leaves the approach sector. After aircraft fly through the approach sector, they reach the merge sector where the aircraft are finally sequenced in order of their landing and runway usage. In the merge sector, the longitudinal separation between aircraft is determined and a minimum of a three mile separation is maintained. From the merge sector, aircraft fly to the ILS glide slope for the final touchdown on the runway.

This modeling view of the terminal area traffic control system is fairly realistic and well represents the current system. In fact, Washington National approach control is designed exactly this way. In this system, two holding stacks each feed an approach sector; the approach sectors feet the merge sector which feeds the ILS glide slope. After the aircraft departs from the ILS gate, it continues to descend the glide slope until it reaches the decision point. If the runway is vacant, a normal landing will ensue; otherwise, the aircraft must wave-off. After the aircraft lands, the ground turn around time is generated and the aircraft enters the take-off queue for departure. The model includes the departing aircraft until it clears the runway.

SIGNIFICANT INPUT PARAMETERS

The simulation model is designed so that the input parameters completely define the air terminal system to be simulated. The various parameters that define the ATC system are as follows:

1. Aircraft performance parameters
2. Airway geometry
3. Traffic generation
4. ATC standards and procedures

Aircraft performance parameters that interact with the ATC system are basically the nominal flight profile, limitations, speed range and procedures. These parameters are obtained from the aircraft performance table. These performance characteristics are useful in studying the effect of traffic mix on the operation of the ATC system. For the terminal area simulation, the arrival and departure routes that constitute the normal traffic problem within the terminal area have to be defined. The approach sectors, merge sectors, glide slopes length, and the standard instrument departure routes define the airway structure of the terminal area.

A major input of the model is the sample of traffic which the system must process. Realistic samples are generated by a random arrival using a Poisson process. Inputs of the model include the distribution of type of aircraft, ratio of arrival and departure in given hour of operation, and the rate of arrival for a given hour. Traffic samples can be controlled by varying the input parameters in order to study the effect of varying demand structures.

The ATC standards are defined by the separation requirements and the navigational techniques in the terminal area. These are specified in the FAA publication. (11) The ATC procedures have direct impact on operations. These procedures include rules for collision detection and avoidance, the aircraft sequencing policy, route structure, and the runway assignment policy, issuance of landing and departure clearance, etc. These ATC standards and procedures completely define the operations in a terminal area.

DESCRIPTION OF THE SIMULATION MODEL

The simulation model utilizes the event to event simulation philosophy. Each event includes consideration of system components and subsystem interactions which have an effect on the event.

Each aircraft in the terminal area is defined by a vector of variables, or attributes, which are stored by the GASP in a file structure. One file has been established for each sector to store aircraft which are in that area. For instance, one file contains aircraft in holding stacks, another contains aircraft on the ILS glide slope, etc. GASP automatically collects statistics on the time aircraft spent in each file and on the number of aircraft in each file. The file structure is, therefore, a convenient means of segregating aircraft according to where they are in the terminal area, as well as a means of collecting some of the statistics required to analyze air terminal operations.

The events represent the aircraft flight in different sectors of the ATC operations. Events are defined by a set of attributes and are stored by GASP in an event file. Entries (events) in this file are ranked on the basis of event time. GASP removes the first entry in this file and calls the appropriate subroutine to process the event. Each event creates future events as required and stores them in the event file. The operation of creating and processing events is thus internally regenerative and continues until the end of the experiment.

In relation to each of these concepts, and as an introduction to the simulation, consider the flight of an aircraft through the terminal system. The occurrence of an arrival directs GASP to call event ENTER. An example of the regeneration of events is that ENTER creates the event which causes the next arrival. Thus, only one ENTER event needs to be stored, thus, conserving computer storage space. The current arrival is defined and stored in one of the holding stack files by ENTER.

Aircraft are released from the holding stacks by the DEPART event. The logic required to determine which aircraft to release and when is rather complex and depends on the landing sequencing policy and the ATC procedures in effect. When a release can be made, the appropriate aircraft is removed from the holding stack file and stored in the approach sector file. A MERGE event is stored in the event file to initiate processing when the lead aircraft in an approach sector arrives at the merge sector. The ATC function in the merge sector is to "funnel" air traffic approaching from virtually an infinite number of directions into an orderly, "follow-the-leader" configuration at the ILS gate. If the merge sector is operating at capacity when an aircraft arrives at the sector boundary, the aircraft is stored in an in-flight delay file. This delay file ranks aircraft on a first-come-first-served basis, simplifying processing when aircraft in both approach sectors and the wave-off go-round file are delayed. The first entry in the file has priority for release into the merge sector. Event MERGE processes the transition of aircraft from an approach to the merge sector.

Event GATE processes the arrival of an aircraft at the ILS gate. Until this point, geometric locations of aircraft have not been considered as such. Rather, it is assumed that sector controllers do what is necessary to assure safe airside separations so that aircraft fly between event nodes in predetermined time intervals. These time intervals are meant to model the judgments of controllers who maneuver and sequence aircraft in the outer region of the terminal area. The gate is interpreted as an actual physical location. An arrival at this point provides the opportunity to correct possible inaccuracies in prior judgments. The actual time separation between an aircraft at the gate and the aircraft following it is calculated. Pilot and controller errors, wind and weather effects, etc., are thus compensated for at the gate.

At the decision point, the pilot must decide whether or not to wave-off. Event DECIDE processes this decision and causes a wave-off to reapproach the merge sector via the wave-off go-around or allows the aircraft to proceed toward the runway.

The THRES event, defined by the arrival of an aircraft at the runway threshold, relocates the aircraft from the glide slope to the runway file. Actual runway usage time and the exit to be used are also calculated at this time.

Runway exits are processed by the BLOCK event. Landing aircraft are stored in a ground processing file and the QUEUE event processes the aircraft for departure from the system. Aircraft in the departure queue are permitted to take off when the required separations between the last take-off and the next landing are met. Event TOCHK checks for these take-off conditions and initiates a take-off. BLOCK also processes the exit of a departure from the runway.

As previously indicated, the simulation program is written in a modular form. Each event in the simulation is defined by a separate subroutine of the program. Decomposition of the air terminal system into discrete events simplifies the logic of defining each subroutine. For better understanding of the subroutines, a macro-diagram of the flow of operations in each of these non-GASP subroutines is shown in Illustration 1. Since the GASP package is well documented, no attempt is made to describe the details of the simulation program.

OUTPUT OF THE MODEL

The simulation output consists of three parts: a) a list of all GASP and non-GASP input data; b) a printout of attributes of an event, when the event takes place. This allows the analyst to follow the simulation processing event-by-event; c) a summary of simulation results.

The simulation summary gives the following information:

1. Final GASP file summary, specifying the mean, standard derivation, minimum time and maximum time an entry in the file is stored in the file. This information can be interpreted as the average length of time an aircraft spends in a given sector of the terminal air traffic control system.
2. Average delay of aircrafts in each sector.
3. Total number of aircraft in the system by category of aircraft and by hour of the day.
4. Total number of wave-offs by category of aircraft and by hour.
5. Total number of landings.
6. Total number of take-offs.
7. Number of communications between controller and pilot.
8. Total runway idle time.
9. Inter touch-down time.

From the last two outputs, the runway utilization statistics can be derived.

VALIDATION OF THE MODEL

The simulation model has been subjected to a number of tests for complete validation. First it was subjected to internal verification to provide assurance that the model is operating as planned. However, model validation in comparison with real-world data is important for the simulation model. The objective is to determine whether the simulation model output matches the measure of performance of the real life system. For this purpose, realistic data were collected from Atlanta airport. The input data was designed to represent the terminal ATC system of the Atlanta airport. The model was then applied to simulate the present conditions of the airport. Forty simulation runs with varying interarrival times were conducted and statistics were gathered for the system measure of performance. The output of the simulation runs were compared with the actual measure of performance for the Atlanta airport. The comparison implied that the simulation model describes the functioning of the system under the present condition. For example, in Atlanta airport, the average delay in landing during peak hours of operation is 10 minutes and the average delay generated by simulation is 10.64 minutes. In this situation, the sample mean is within 95 percent confidence interval from the universe mean. Other statistics have been generated and compared with equally favorable results. This assures that the model generated output will be useful in realistically analyzing the terminal ATC system performance.

IV. APPLICATION OF THE MODEL

The simulation model was developed to furnish a tool with which to study the terminal ATC system. Many decisions concerning the system can be made with the assistance of this simulation model. The model is capable of providing results for analysis of a wide range of terminal ATC problems. For example:

1. The evaluation of terminal ATC performance under various operating schemes.
2. The evaluation of system reactions to increased level of traffic demand.
3. The analysis of runway expansion program.
4. Sensitivity study of such model parameters as separation standards, airway geometry, random flight time of aircraft, etc.
5. The quantitative representation of benefits and penalties associated with various operating schemes.
6. The evaluation of design parameters for future equipments.

The operating scheme for a terminal ATC can be defined by the procedures of handling arrivals and departures in the terminal area. Of these procedures, landing sequencing policy and runway assignment policy are used to show application of the model in determining the best operating policy for the Atlanta airport. Six different operating policies can be defined as combination of two different procedures. They are:

1. Sequencing logic
   a) First-come-first-served
   b) Speed class sequencing
2. Runway assignment procedure
   a) Runway segregated by aircraft category
   b) Runway segregated by operations (arrival or departure)
   c) Runway used for all aircraft for all operations

For each of the experiments, the input parameters which completely define the Atlanta airport ATC procedure and the demand structures are kept the same. The arrivals are Poisson distributed resulting in an exponentially distributed interarrival time. The hourly mean arrival rates were the same for all simulation runs. The number of runways and their dependencies were also kept the same and the separation standard used is three miles.

The computer program made multiple simulation runs for a given operating condition. Each operating condition was simulated over a ten-hour-per-day basis for ten days. ATC random number generators were initialized to the same random number speed for each input operating condition. Therefore, all runs had the same demand and sequence of arrival and departure. This permits a direct comparison of the effect of different operating schemes on ATC performance. Table 1 shows the average for selected system measures of performance for the six alternative operating schemes.

At present, Atlanta airport uses the first-come-first-served policy for arrival sequencing and all the runways are used for all aircraft and for both landing and departure. However, the results of the various operating scheme, as tabulated above shows that the performance can be considerably improved if the operating scheme is changed to speed class sequencing with runway segregated by aircraft categories. It should be noted that the statistics presented above are based on ten day runs and longer simulation periods may improve the statistics.

The above result discusses only one application of the model. Similar analysis of other terminal ATC problems can be performed on sensitivity of input parameters, effect of new demand structure, and effect of proposed alternative physical system configuration on system performance.

VI. CONCLUSIONS

The simulation model is developed to furnish a tool with which to study the terminal ATC system. This enables the model to represent the complex interactions among the components of the ATC system. The system approach also enables the model to determine the overall effect of ATC performance as a consequence of any proposed change.

The discrete event simulation using GASP is a unique concept applied to evaluating the terminal ATC system. The GASP simulation language allowed efficient modeling of the complex ATC system with relatively straightforward logic. The use of discrete event philosophy provided a modular format of the computer program which allows changes and additions to be made easily.

The validity of the model with data from an actual airport is conducted and the conclusions of this validatory process suggests that the model adequately represent the operations of a terminal ATC system. These results also indicate that the discrete event modeling of system effects can adequately simulate air-terminal operations. Many decisions concerning the system can be made with the assistance of this model. The results of the model will enable the ATC planners to identify the parts of the system that are restricting efficiency and capability. This model will also furnish the effects of alternative policies and improvements so that the best system configuration and operating procedures can be identified.

ACKNOWLEDGMENTS

This research was performed by the Civil Engineering Department of Virginia Polytechnic Institute and State University as part of the National Science Foundation Grant No. GK-30325. The authors are considerably indebted to W.E. Wiehelm for his assistance in formulating the initial model for this research project. The opinions expressed in this paper are those of the writers and are not necessarily those of the sponsor.

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ILLUSTRATION 1

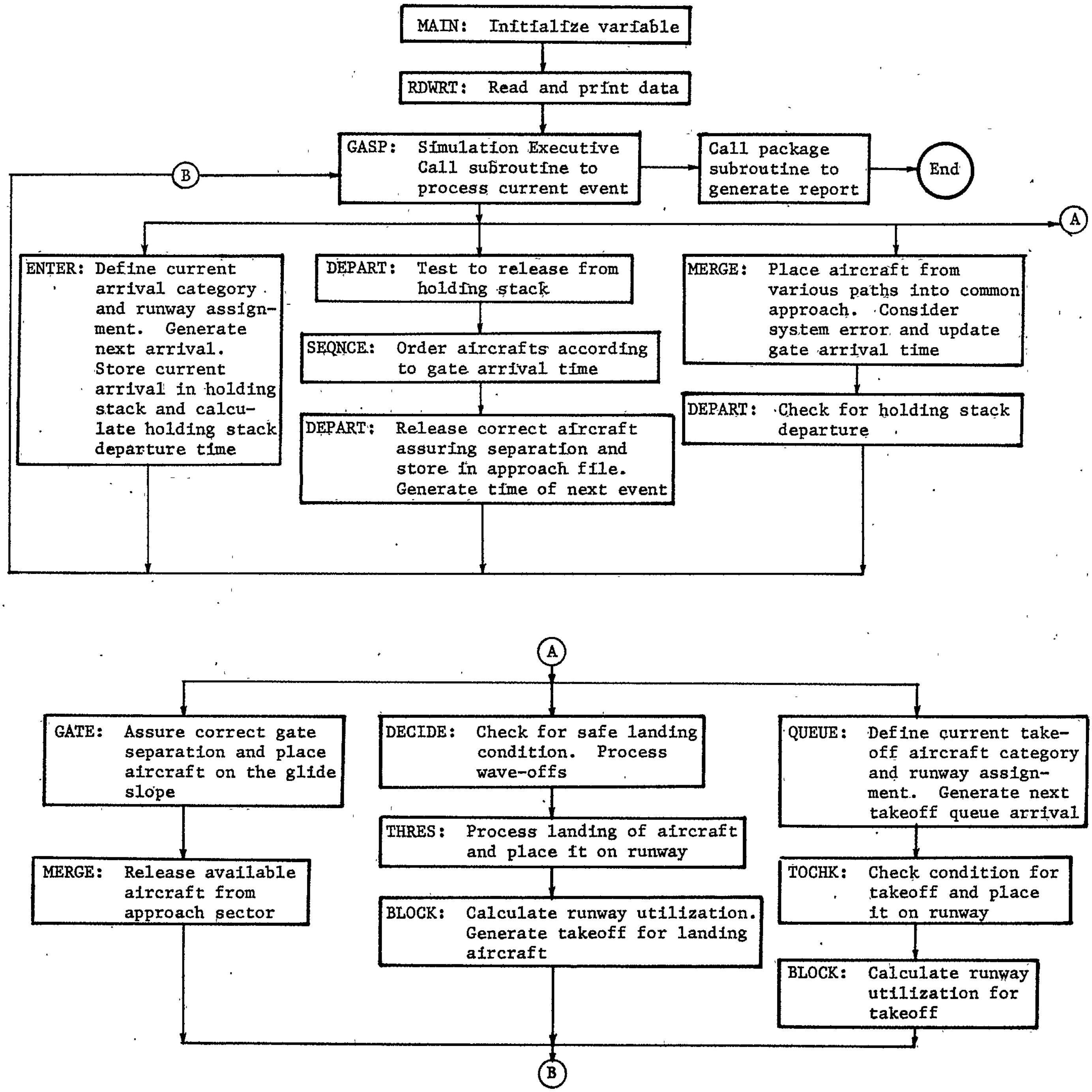

TABLE 1

Operating scheme	Average delay in landing (min)	Average delay in take off (min)	No. of communications per hour	No. of landings per hour	No. of takeoffs per hour	Runway utilization time per hour
First-come-first-served with Runway segregated by aircraft	9.38	3.92	61	44	31	27.37
First-come-first-served with Runway segregated by operation	9.87	3.07	69	31	46	22.83
First-come-first-served with Runway used for all aircraft for all operations	10.69	4.18	83	31	29	20.02
Speed class sequencing with Runway segregated by aircraft	7.42	5.11	86	53	27	33.16
Speed class sequencing with Runway segregated by operation	8.12	5.06	93	44	35	29.06
Speed class sequencing with Runway used for all aircraft for all operations	8.73	6.99	108	39	19	26.74