GPSS SIMULATION FOR AIRPORT CAPACITY AND FACILITIES EXPANSION ANALYSIS

Charles A. Willis
Senior Systems Analyst
Hudgins, Thompson, Ball and Associates, Inc.
Aviation Services Division
Oklahoma City, Oklahoma

Abstract

GPSS simulation of a major air carrier airport to provide an analysis of capacity of the runway and taxiway system and determination of delays encountered at peak levels of traffic activity. Alternate airport expansion schemes were developed and examined through the simulation technique and a concept for expanding operational capacity was selected. All essential elements and functions of the airport were contained in the model.

1. INTRODUCTION

During a recently completed airport expansion study the planning staff of Hudgins, Thompson, Ball and Associates, Inc., through its Aviation Services Division, was confronted with two major tasks:

(1) To analyze the flow characteristics of aircraft ground traffic through a complex network of runways, taxiways and aprons, and to determine the capacity for the existing system, and

(2) To develop expansion schemes which would minimize investment on the existing site yet permit increased numbers of aircraft operations through 1980, when a new facility on a new site would be available for operations.

The airport studied is one of the busiest in the nation, but it has been hampered throughout its growth by haphazard implementation of improvements, and inadequate long-range planning. The result was a 1300-acre enclave surrounded by high density residential and industrial development, which effectively prevented immediate physical expansion and necessitated development of any additional runways or aircraft operating surfaces within the perimeter of the existing airport. It was decided that due to the complexity of the system and operational characteristics, a departure from conventional methods of analysis would be necessary. Traditional methodologies for airport capacity analysis are essentially academic, heavily dependent upon subjective judgments by the analyst, and in reality, suitable only for fairly uncomplicated systems. Additional shortcomings are:

- Traditional methods of analysis are based on average data developed from observations at various types of facilities. While these methodologies provide general guidance, they do not provide specific information for a specific facility. In addition, the capacity of a system is dependent upon the specific mix of aircraft using the facility. Interpolation of charts and graphs may not provide the correct input data for a capacity analysis of that facility.
- Traditional methods are based on the assumption that traffic flow is uniform. The effects of congestion cannot be analyzed objectively, due to the large number of variables; and, since ground congestion is one of the major causes of aircraft delays, it cannot be dismissed. Traditional methods may have little or no provision for congestion adjustment, and consist largely of relating a given number of operations to a given runway system configuration. The most limiting aspect of this approach is that unless the analyst is extremely knowledgeable in aircraft movement techniques employed by control tower operators and aircraft operators, he may have a tendency to under estimate critical relation-

ships within the alternative solutions.

- A substantial effort is required to thoroughly examine alternative runway, taxiway, or apron configurations. Each configuration requires separate analysis. Since most alternatives for airport expansion are usually developed around an existing or basic runway configuration, analysis of alternative solutions usually depends heavily upon analysis of the basic system with minor adjustments inserted to reflect the alternative configuration. This approach may satisfy the analyst, but it is unrealistic in terms of the real system.
- Of great importance but frequently overlooked are the gate position utilization requirements for air carrier aircraft. Gate utilization times may vary substantially, and an aircraft waiting to enter a gate may block traffic in such a way that the entire airport may be affected. While it is possible through intuitive analysis, to locate areas of potential congestion and tight maneuvering, congestion does not always occur at the most obvious location.

2. SIMULATION OBJECTIVES

In order to provide a more meaningful analysis of existing airport capacity, as well as determination of the effects of alternative runway and taxiway configurations, it was decided to investigate the application of computer simulation modeling techniques to the problem. The objectives in the development of such a model would be to eliminate as many of the shortcomings of traditional analytical techniques as possible, and to present an analysis which would reduce subjective and arbitrary judgments on the part of the analyst. Specific goals included:

- A dynamic analysis of the existing system under current and projected levels of activity
- The dynamic capacity of the airport, on an hourly basis, as influenced by preceding and succeeding hours
- Objective evaluation and selection based on system performance of alternative expansion concepts
- Identification of operationally critical areas in alternative solutions and the characteristics of the system's operational functions, which cause the criticality
- Statistical operations data such as delays, queue lengths, areas of congestion, gate utilization times and traffic flow
- Development of an analytical tool which can be revised and refined to provide a basis for capacity and systems flow studies at other airports

2.1 LANGUAGE SELECTION

In order to assure reliability of alternative expansion concept testing, it was necessary to construct a model of the existing facility which would perform in a manner analogous to the real system, and development of specifications for the level of detail to be depicted within the model was a major consideration in selection of a modeling language. Since the programming language for simulation dictates to some degree the character and methods for acquisition of input data, a substantial amount of time was spent investigating available simulation language and techniques.

After a thorough investigation of available simulation languages, including SIMSCRIPT, the decision was made to use GPSS/360. Tests of language compatibility and flexibility were conducted using test modules of the system, and GPSS was felt to possess the versatility, reliability and ease of programming necessary to produce a model of sufficient detail and sensitivity. Since programming man-hours were limited, GPSS proved to be of great value because of the ease with which the system and its sub-systems could be translated, and also the relative ease with which the programs could be debugged. After flow-charting the model, it became apparent from the size of the network that the locally available data processing equipment (128K 360/40) would not have sufficient capacity to perform under load with the entire program intact, and the decision was made to develop the model in modules and test each segment separately.*

This decision proved beneficial in that a higher degree of validity and reliability was achieved when the modules were finally assembled, and the time required for program error elimination was substantially reduced.

2.2 MODEL DEVELOPMENT

Preliminary analysis indicated that it would be desirable to examine system performance over a period of 24 hours, which would permit simulation of daily peak operating conditions, as well as inclusion of a significant number of operations which remain overnight. It was felt that a 24-hour time period would permit consideration of aircraft remaining overnight in gate positions, as well as general aviation aircraft departing during peak hours of the morning. The average operations and current levels of activity were nearly 400 daily, with the vast majority (approximately 80%) occurring during a 15-hour period from 8:00 a.m. to 11:00 p.m. Peaks of operations occur at approximately 9:00 a.m., 11:00 a.m. and 4:00 p.m. These peaks are characteristic of traffic flow at many airports, and are primarily a concession to the demands of business travel. Projected activity for future operations which would be simulated were programmed on a similar distribution.

To be of value, the model must satisfactorily simulate the critical elements which constitute the real system, such as the random and scheduled aircraft arrivals and departures, multiple decision

* The original network contained over 1,000 blocks. This number was reduced during final runs to less than 800. An IBM Model 360/65 with 512K storage was used for final simulation runs.

points (i.e., several taxiways intersecting at one point, 2-way or 3-way movement of aircraft at a point, etc.), and to provide statistical output of measurements at selected locations and under particular types of operations. Aircraft were to be identified as to type, category and operators, and the program designed to accept changes necessary to accommodate projected activity. Aircraft performance data would be used to define the operating characteristics necessary to present a reasonable analog of aircraft movements, as well as to provide realistic spacing of arriving and departing aircraft. It would also be necessary to provide a system to route arriving and departing aircraft to appropriate locations on the airport. An examination of the physical characteristics of the airport system resulted in the development of a node and connection network from which operating aircraft movements could be analyzed. Approximately 110 nodes or intersections were devised and were based primarily on runway, taxiway and apron physical properties. A diagram of the physical layout of the airport is shown in Figure 1.

In order to establish a framework for program definition and analysis of existing airport operations, a facilities diagram was prepared to study operating procedures. Observations and measurements were made over a period of ten days for every type and category of movement. Patterns of movement were carefully recorded, and procedures used for special or unusual situations were thoroughly discussed with traffic controllers to determine the logical rules. Vantage points for the observations included control tower, apron, taxiway and airport perimeter locations. All intersections and crossing points for traffic were carefully defined on the diagrams and movement times between the nodes recorded. Delays at all points of the airport were carefully recorded and included descriptions of causes and resolutions observed. Overlay diagrams were constructed for all the using aircraft at the airport, to confirm survey data and to determine primary and secondary utilization patterns.

The nodes or intersections of paths of traffic movement were defined as storages with the capacity of each determined by the physical dimensions of the real facility, but was modified by parametric identification of aircraft type. For example, a given intersection may possibly accommodate two DC-9 aircraft simultaneously, but would be filled if a single Boeing 707 were to enter. Runways were defined as facilities due to their unique operating requirements, which are substantially different from other aircraft operating surfaces. Once given priority to land (seize the facility), an aircraft attempts to clear the runway at the first exit appropriate to the aircraft type. However, a test of taxiway routes is conducted prior to exit and unless that taxiway routing is available, the aircraft will continue to the next succeeding exit and test again. In some instances as many as 15 storages were tested prior to entry into a chain of storages which composed the taxiway system between the runway and the gate position.

The decision-making apparatus for the tests consisted of parametric identification (air carrier or general aviation, jet or propeller-driven,etc.) as an entering argument, and utilized boolean variable statements or random variable statements where several paths were possible. Many intersections had as many as five alternate paths which, due to the two-way traffic possible, would permit ten possible transactions seeking access to the same intersection simultaneously, and the testing of chains of storages prevented congestion due to simultaneous arrivals. The close interrelationships of these storages during high levels of operation required consideration of the interaction of one system of storages upon another, and flow charting was an excellent aid in cross checking the definition of the relationships and in definition of sub-system interfaces. Approximately 50% branching occurred in the final model.

Gate positions on the airport were also defined as storages with a capacity of one aircraft each. Delay times were programmed to prevent the aircraft as identified by flight number, type, operator, from departing the gate earlier than his scheduled departure time. If an aircraft arrived at the gate early, it would be held until the scheduled departure time; however, an aircraft arriving late would remain on the gate for a minimum time, as determined through interviews and observations of each carrier's operations, and depart late.

General aviation aircraft were routed to the general aviation parking area, and arrivals and departures programmed to coincide with existing general aviation traffic activity characteristics.

First programming efforts were directed toward development of aircraft generation functions to coincide with existing air carrier schedules and current non-air carrier patterns of usage. A separate generate statement was used for each scheduled air carrier with the generate interval defined by list-valued functions. This technique permitted irregular intervals of aircraft arrivals and departures, as well as permitting random variation in arrival times, to realistically depict actual aircraft operations.** Non-scheduled aircraft were generated at random intervals, but grouped within a 15-hour period in which peaks of unscheduled activity occurred historically. Performance data for these functions was derived from actual observations, airport and air traffic control personnel surveys, and from airport statistical data. These transactions were also generated with list-valued functions.

Aircraft arrivals outside the real airport system affect operations to the extent that spacing by

** Arrivals and departures were limited to 15 minutes either side of scheduled times. This criteria is consistent with the Civil Aeronautics Board definition of an on-time operation.

air traffic controllers reduces densities of operation within a given time period and allows a smoother flow in and out of the system. It was felt that in this model, due to size restrictions and core capacity limitations, no effort would be made to program the controlling factors beyond the point where an aircraft is normally committed to land. This point was defined to be approximately three miles from the center of the complex for large air carrier aircraft and approximately one mile for small aircraft. These distances result in approximate spacing of one minute for successive operations of aircraft within the same category, and aircraft holding outside of the system were placed in a queue. These intervals are subject to some variation, primarily due to interleaving of arrivals and departures, and to variations programmed into runway utilization times. The time required for a departing aircraft to take the runway, accelerate and pass over the departure end of the runway, will vary with type and category. For example, the Boeing 727, as determined by actual measurement, will require from 14 to 18 seconds to accelerate and take off, and some additional time to pass over the end of the runway; while a small aircraft such as a Cessna 172 will require somewhat less time to take off, but due to its slower airspeed, will take much longer to reach the end of the runway and exit the system.

The program was written in such a way as to permit the interleaving of arrivals and departures, but each was dependent upon a test of runway availability. If the runway was being used by a departing aircraft and an arriving aircraft wished to use the runway, the arriving aircraft would be held approximately 30 seconds after the runway was clear. Succeeding aircraft desiring to land would test the queue line and, if an arriving aircraft was already awaiting entry, the second aircraft would be held approximately one minute behind the first aircraft. This method permitted analysis of queue length during peak levels of operation.

3. RESULTS OF SIMULATION

Due to the physical and financial constraints to expansion, all but one of the alternatives developed on a conceptual basis were found unacceptable. The surviving concept for increased capacity was an additional parallel runway (see Figure 1) oriented east-west and designed primarily as a reliever runway for general aviation usage. The emphasis on simulation was shifted slightly from evaluation of alternatives to an evaluation of system performance with the new runway installed. Crossing problems at the primary east-west runway were felt to be a major consideration in the success of the proposed development, and it was felt that there was sufficient justification for simulation of this single aspect of system development.

As indicated earlier in this paper, the final phases of model development were to produce a simulation which would accurately represent existing facilities under current operating conditions, and then to test expansions or modifications to the system. Developmental testing for reliability and validity accumulated approximately two hours CPU time on the IBM Model 65, with the average time per run approximately three minutes.

Final simulations of the airport were conducted in four configurations:***

I. The level of daily traffic was increased to 1970 levels of operation without facility modification.
II. A proposed new runway, high-speed runway exits and additional taxiways were added, and the apron area enlarged. Traffic was increased to 1975 levels.
III. Traffic was increased to 1980 levels with the new runway removed. The number of gate positions remained at 35.
IV. The 1980 traffic level was maintained and the proposed new runway was added. Gate positions were increased to 40.

Simulation runs in Configuration I were made to determine how the unimproved facility would respond to near-range increases in traffic. Present schedules and levels of operation were expanded incrementally to achieve 1970 conditions. The model responded to these traffic increases by developing congestion at several key points in the terminal area. The most critical areas involved the taxiway at the west end of the west concourse, the taxiway north of the north concourse, and the taxiway intersection north of the fuel truck parking area. Each area experienced delays of 40 minutes or more. Secondary congestion occurred in the area between the existing concourses. Aircraft traffic in this area approaching gates or attempting to reach the south side of the west concourse experienced delays of 5.46 minutes to 10.51 minutes.

By increasing the number of gates to 35, congestion was reduced and a substantial improvement in circulation within the terminal area was realized. Aircraft passing the west concourse still experienced delays of up to 4.13 minutes. Average gate utilization times ranged from 36.61 minutes to 37.85 minutes.

Delays to landing and departing aircraft at the runways were significant. Of the aircraft using runway 01-19, 67.9% experienced no delays, as did 71.5% of those using runway 10-28. Of all the aircraft using runway 01-19, 22.7% were delayed in excess of 5 minutes, and 21.0% of those using runway 10-28 were delayed for 5 minutes or more. Maximum queue length was three on runway 01-19 and two on runway 10-28.

In Configuration II, the proposed new runway was added, along with high-speed runway exits and ad-

*** CPU time required for these runs ranged from 3.63 minutes to 3.80 minutes. Total machine time for the entire project was 3.6 hours on the Model 360/40 and 2.9 hours on the model 360/65.

ditional taxiways. This configuration is shown in crosshatch on Figure 1. The addition of the new taxiway parallel to runway 10-28 resulted in a substantial increase in utilization of the area where this taxiway intersects the apron near the west concourse. Approximately 82% of all aircraft using the airport passed through this area. This apron also provides access to and from the existing and proposed west concourses, cargo area and general aviation parking. Delays to aircraft movement encountered in this area reached 20.2 minutes, until the apron was enlarged to permit three lanes of traffic flow.

The introduction of the new runway reduced the maximum queue length at runway 10R-28L to one, but the number of aircraft experiencing no delays was reduced to 39.4%, due to the requirement of staggered operations on close parallel runways. Maximum queue length on runway 01-19 remained at three and no delay entries remained at 67.9%. No delays were encountered by aircraft using the new runway. The number of gate positions remained at 35, and provided satisfactory capacity. Distribution of runway utilization was: runway 01-19, 72.21%; runway 10R-28L, 16.72%; (proposed) runway 10L-28R, 11.07%.

Configuration III was run to determine how the facility would respond to 1980 traffic levels with improved apron, terminal facilities, high-speed exits and taxiways, but with the proposed reliever runway removed. Delays to aircraft utilizing the runway system increased substantially. On runway 01-19, the percentage of aircraft encountering zero delays was reduced from 67.9% to 32.6%, with 30.4% delayed more than five minutes. One hundred percent of the aircraft using runway 10-28 were delayed, although delay times on runway 10-28 were shorter (averaging two minutes per aircraft) because of superior taxiway configuration and lower runway utilization. Runway 01-19 was used for 68.5% of the total operations and runway 10-28 for 31.4% of the total operations. Maximum hourly operations achieved under this configuration were 73 of which 55 were air carrier operations.

During this run, marked increases in transit times from point to point occurred throughout the model, with some congestion developing in the area between the concourses and in the taxiway which crosses runway 10-28, directly north of the terminal. Queues in this area totaled 20 aircraft at one time, during the run. This congestion was caused by an insufficient number of gate positions and was eliminated by the addition of five gates, which increased the total number of gates to 40. Gate utilization times averaged from 37.22 minutes to 40.20 minutes.

Configuration IV simulated the improved facilities at 1980 traffic levels with the proposed runway in service and with 40 gate positions. No significant ground delays occurred during this run and 40 gates satisfied the demand. Gate utilization times averaged from 35.0 minutes to 38.0 minutes.

The addition of the new runway 10L-28R reduced aircraft delays and increased the percentage of zero delay entries to runway 01-19 from 32.6% to 59.7%. Zero delays to runway 10-28 were increased from zero to 36.0%. Percentages of runway utilization were: runway 01-19, 65.38%; runway 10R-28L, 16.0%; (proposed) runway 10L-28R, 18.62%.

These utilization figures clearly show that the proposed runway will carry a substantial portion of the projected traffic and will permit the two principal runways to be used primarily by air carrier aircraft. Peak air carrier hourly operations achieved was 55.

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The underlying philosophy of the development of the model was to represent the airport as realistically as possible under peak operating conditions. Radical changes in aircraft types, changes in route structure and route interaction, passenger preferences, generation and allocation of demand, airport limitations in cargo and passenger handling facilities, and cost are all variables which cannot be reasonably included in this simulation. It is stressed, therefore, that this simulation is considered primarily a tool to aid in planning. The logic which controls this simulation is a realistic analog of the logic that controls the elements of the real airport operations. However, the complex interrelationships between those areas previously mentioned are beyond the scope of this simulation.

4. CONCLUSIONS

Conclusions reached on the basis of the computer simulation are:

- The computer simulation substantiates the facility expansion concepts recommended.
- Apron expansion and additional gates are the most critical short-range improvements.
- High-speed exits, additional taxiways, and a general aviation reliever runway are essential for efficient operations beyond 1972-1973.
- Anticipated traffic increases will exceed the capacity of the improved facility by 1980.

BIOGRAPHY

Mr. Willis is a Senior Systems Analyst for Hudgins, Thompson, Ball and Associates, Inc., an architectural and engineering firm in Oklahoma City. He has been engaged in a broad range of activities relating to airport and aviation facilities design and development, and has been primarily concerned with the application of operations research techniques to facilities functional design. This includes systems analysis, simulation, network definition and analysis, CPM and other management tools.

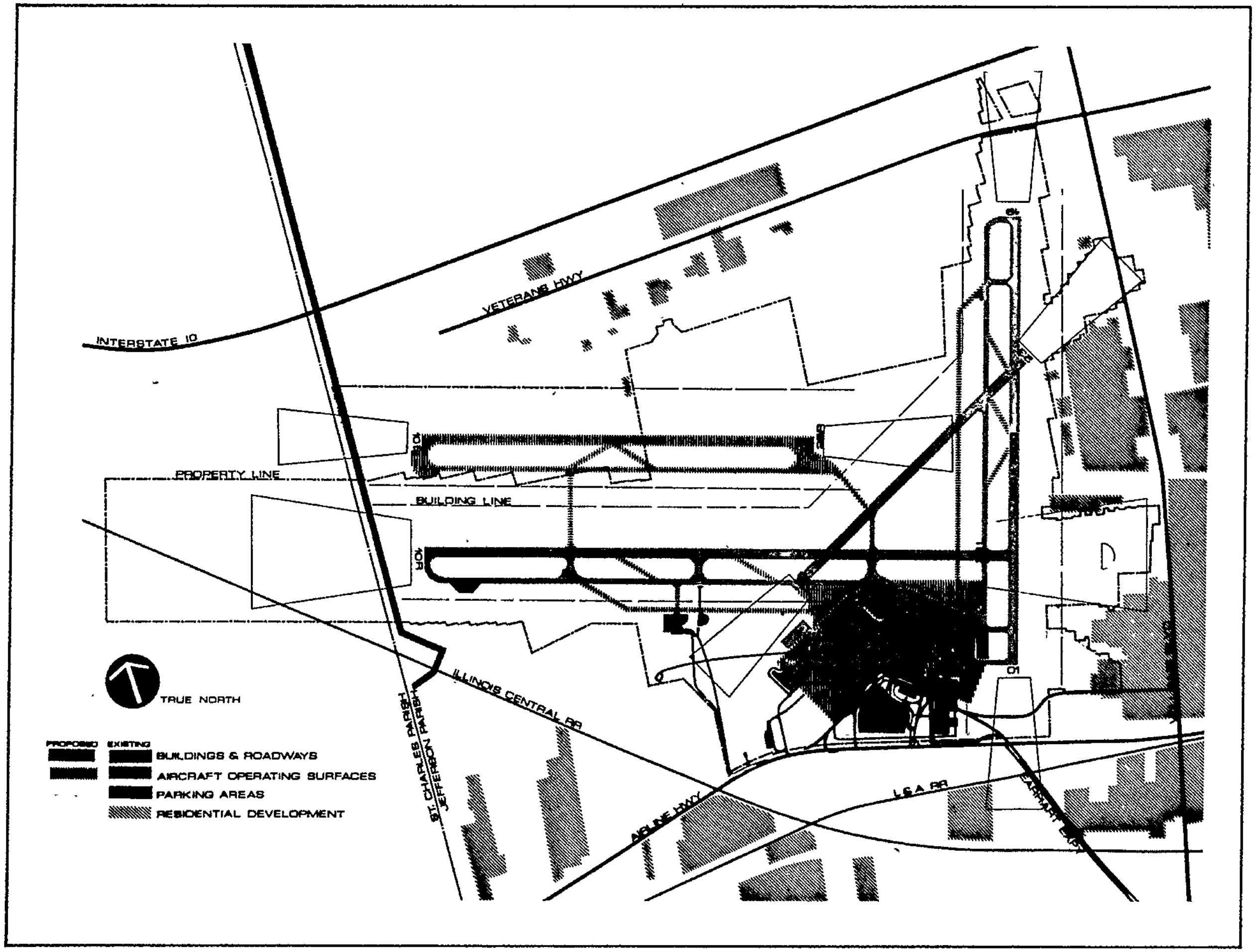

FIGURE 1 - NEW ORLEANS INTERNATIONAL AIRPORT
EXISTING AND PROPOSED RUNWAY CONFIGURATIONS