a place to arrive and depart by air but also as a place to shop, to work, and to conduct business.

FUTURE PROBLEMS

Previous studies have indicated that there are four prime issues in landside planning for airports (see Figure 1):

1. Origins of trips from home or work to the airport are so dispersed in urban areas that few, if any, justifiable transit corridors exist to facilitate the trip linkage between home or work and the airport. This makes it necessary to use private, semipublic, or public vehicles on the road system to effect the linkage, which further adds to demands for more and better highways.
2. Few major regional airports have more than one major highway linkage to the major regional highway networks. This adds to the problems of congestion and delay during hours of peak airport use, work-shift changes, and so on.
3. Too much parking has been placed in the central terminal area in close proximity to the airport terminal for a proper balance among terminal capacity, parking capacity, and roadway capacity. This further increases congestion and confusion in the central terminal area.
4. Too much pressure is placed on enplaning and deplaning linkage between vehicles and terminals. Curb frontage is perhaps the most precious real estate at any airport terminal facility because of this great need.

In my opinion, there are institutional constraints that are also paramount in the proper development of new and improved airport facilities. These constraints involve the interaction between the government groups responsible for airport planning and development. Airport development is largely supported by federal funds. Formulas have been conceived to facilitate this development, but they are not realistic, acceptable, and fair in all cases. This fact alone causes great concern among many people and results in animosities and disputes that stymie good, timely airport planning and development. Funds that were designated to be spent on the basis of zero-budget funding are thus encumbered and not used as intended.

Federal regulations are, in many instances, misused to delay airport development. Environmental impact statements alone can set back an airport program for as much as 10 years. It is easy to see that, when the growth of patronage continues and airport improvements are delayed, the problem is further compounded and the losers are usually travelers, their businesses, and their families and ultimately, in some cases, the community and the owners of the airport complex. From my vantage point, the most difficult institutional problem is the inertia and discord among airport planners, sponsors, and benefactors. It is unlikely that major changes or improvements will occur, but I believe that, if funding mechanisms at the federal level could be more streamlined and funds used more readily for their intended purposes, it would offer the greatest challenge and benefit to airport growth and development.

Another paramount issue in improving airports and expanding existing ones relates to the groundside components of roads, parking facilities, intra-airport transportation, and pedestrian linkage between the automobile and/or public transportation and the airport terminal building. Employee parking must be differentiated from public parking. Public parking should be differentiated as to short-, medium-, and long-term duration. Short- and medium-term parking should be accommodated close to the terminal; in most cases, long-term parking can be more remote from the terminal and some shuttle bus service can connect interim origin and destination at the airport.

Travel needs know no fixed areal subdivision, ownership, or municipal boundaries. Highway planning and fixed-rail planning for access to airports tend to be jeopardized because of the infrastructure of planning responsibility, airport ownership, and regional transportation development needs. Most airport road systems are primarily planned only by the owner, to the boundary of the airport property. The state or city or county responsible for the roads that lead to the airport from the regional network of highways is then responsible for the external road system. Case history after case history clearly emphasize the resulting breakdown in the planning and facilitation of roads that link highways and airports. In my view, if some changes could be made uniformly throughout the country to give the responsibility for airport access to a single agency, this situation would be markedly improved.

ACKNOWLEDGMENT

Reference material used to research this paper was extracted from a number of airport planning projects designed by Wilbur Smith and Associates and from views expressed at the 1976 Conference on World Airports, sponsored by the Institution of Civil Engineers, in London.

Publication of this paper sponsored by Committee on Airport Landside Operations.

Decision Tool for Analysis of Capacity of Airport Terminal Buildings

B. Frank McCullough, Department of Civil Engineering, University of Texas at Austin
Freddy L. Roberts, Austin Research Engineers, Inc., Austin, Texas

A systems approach to the analysis of the airport system is presented. Airport managers currently do not have a viable tool for determining the effects on capacity of altering the location, operation, or design of individual components within an airport. Models currently exist for analyz-

ing airside capacity, but there has been no means available for comparing and balancing the capacity of all landside components. The technical literature does not contain a method for analyzing these units as a system. A new definition of the airport system and a new systems-analysis-based definition of capacity in relation to level of service are presented, and an algorithm and a computer program that analyze the flow of passengers through the airport system as a function of time are discussed.

Currently used methods of analyzing the capacity of airports may be termed a "component approach". In these methods, analytical models and simulations are used to determine the capacity of an individual component independent of the rest of the airport system. The problem with using such an approach is the absence of a mechanism for balancing flows in all the components, which results in providing excess capacity in some components and congestion in others.

The alternate approach to the problem of determining airport capacity is a systems approach. The systems approach forces the analyst to use a broader, more comprehensive frame of reference than that typically used in air transportation. Thus, the capacities of the individual components are computed and compared and all the components can be balanced.

A systems procedure for analyzing air terminal flow has been presented in a series of reports that were part of a research project sponsored by the U.S. Department of Transportation (DOT). A report by Gualda, McCullough, and Dunlay (1) outlines the basic modeling for the components. Chmores and McCullough (2) report on the collection, at a number of airports, of data that were used for model development and verification. Park and Dunlay (3) report on the development of models for intervening activities. Chambers and McCullough (4) report on the overall computer program and the development of a user's manual. These reports should be examined for a detailed explanation of the study.

The objective of this paper is to present an overall summary of the ACAP1 program and briefly demonstrate its capabilities and applications. More detailed information on the procedure is available in the development reports (1-4).

APPROACH TO THE PROBLEM

In a systematic approach to design, the limits of the system are first defined, then various approaches to capacity are discussed, and finally the approach used in the study is selected.

Airport System

For the purposes of this research, the airport has been designated as a system whose boundaries are specified as the airport entrance gate on the landside and the airspace under the control of the approach-departure air traffic control facility on the airside. However, sites of general aviation activity as well as sites of other noncommercial passenger-related airport activity, such as air cargo facilities, mail-handling facilities, and government agency and airport administration areas, are not considered.

To analyze a large, complex system such as an airport, it is necessary to divide the system into subsystems. In this study, the airport system was divided into four subsystems: (a) the on-airport access-egress subsystem, (b) the terminal building subsystem, (c) the apron subsystem, and (d) the airside subsystem.

The on-airport access-egress subsystem entails the movement and storage of vehicles that enter the airport grounds and proceed directly to the terminal building curbside or parking area. In this subsystem, the processing unit is vehicles. Within the terminal building subsystem, the processing unit changes from vehicles to passengers and baggage. After they are processed through the terminal building subsystem, passengers and baggage move into the apron subsystem, where both the loading of passengers and baggage and the cleaning and servicing of the aircraft occur. Here the processing unit changes from passengers and baggage to aircraft. The airside subsystem includes the movement of aircraft from the apron to the boundaries of the terminal airspace.

Because many activities occur in each of the subsystems, it is necessary to further divide each subsystem into individual components. In systems engineering terminology, a component is the smallest element into which a system is divided for the purpose of analysis. In this paper, the term "component" is used to describe an individual processing or storage unit.

A schematic representation of the airport system is shown in Figure 1. It should be noted that in the past most schematic diagrams of airports depicted an exact functional flow through the different components, especially in the terminal building, but this is not the case in Figure 1. The subsystems are fixed close to actual flow paths, but their exact linkages are left unspecified. The exact linkages between components are not defined in order to provide flexibility in adapting the system definition to any airport configuration.

This paper deals only with the terminal building subsystem and those components within the terminal building that are involved with passenger movements from the building entrance up to and including the jetway into the aircraft.

Airport Capacity

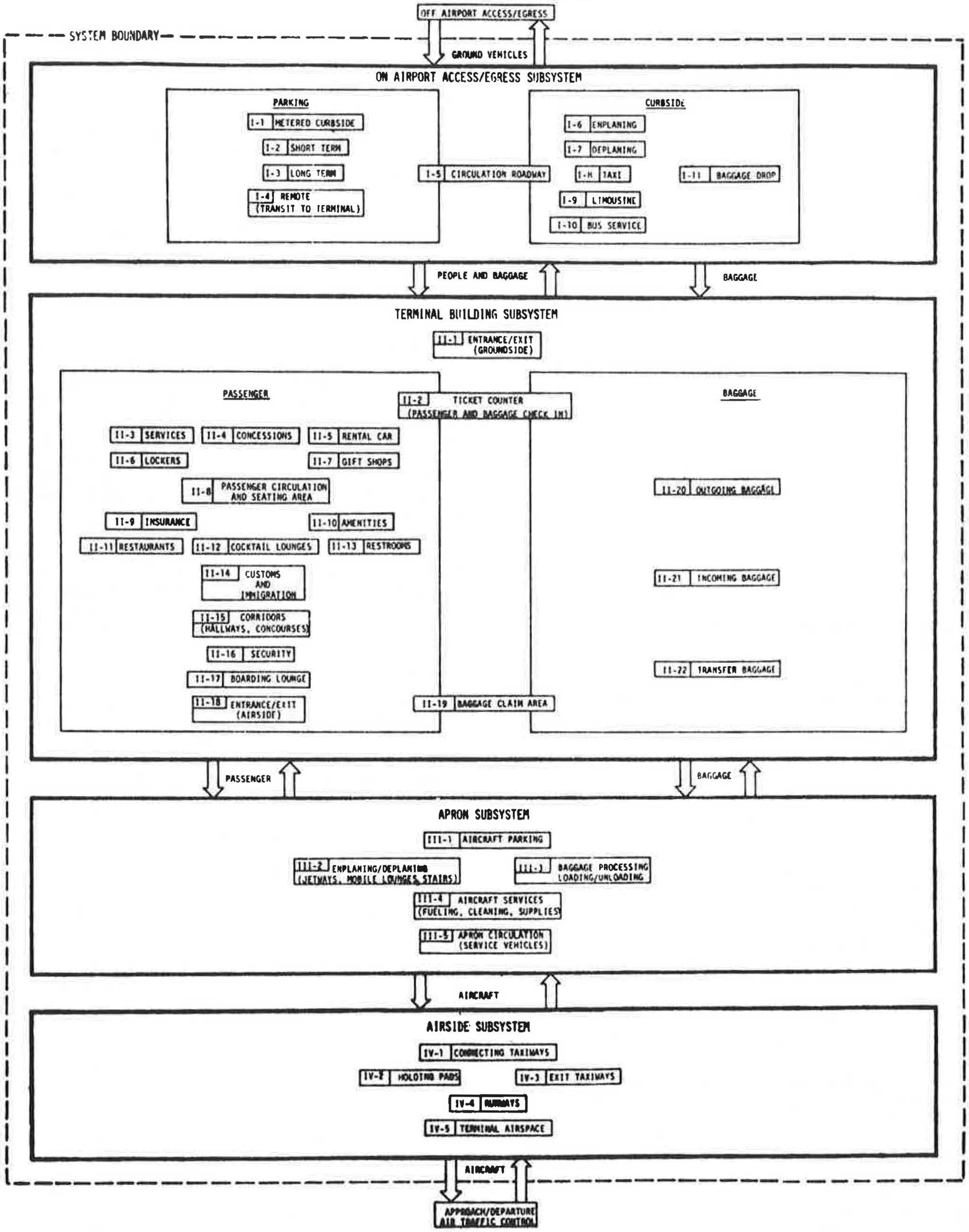
Capacity is an index of the performance and capability of an airport in servicing the processing unit. Historically, the capacity of an airport was assumed to be limited by the airside operation. As a result, research and development in airport capacity have concentrated primarily on airport runways and gates. However, the growth in the number of passengers processed at airports has shifted the emphasis of the capacity problem. There is increasing evidence that the landside is becoming the constraint on airport system capacity. Because of the prior work in airside capacity and the shift in emphasis to the landside, the terminal building subsystem was chosen as the starting point of this research study.

As it became evident that the landside was becoming the constraint on capacity, DOT asked the Transportation Research Board to convene a workshop conference to discuss problems that relate to airport landside capacity. The subjects for consideration at the 1975 workshop included (a) level-of-service methodologies to quantify airport landside capacity, (b) engineering techniques to increase landside capacity, and (c) analytic tools for use in improving landside level of service.

A review of papers presented at the conference (5-8) shows that it is becoming increasingly common to consider capacity with a corresponding level of service. For example, Heathington and Jones (5) point out that, "Capacity is the physical provision required for a given demand at a given time at a specified level of service" and "When capacity is defined as ultimate or maximum capacity, it is generally associated with the lowest level of passenger service." This concept is similar to the concept of highway capacity (9).

In order to develop a capacity that relates to level

Figure 1. Generalized schematic representation of the airport system (flow lines omitted).



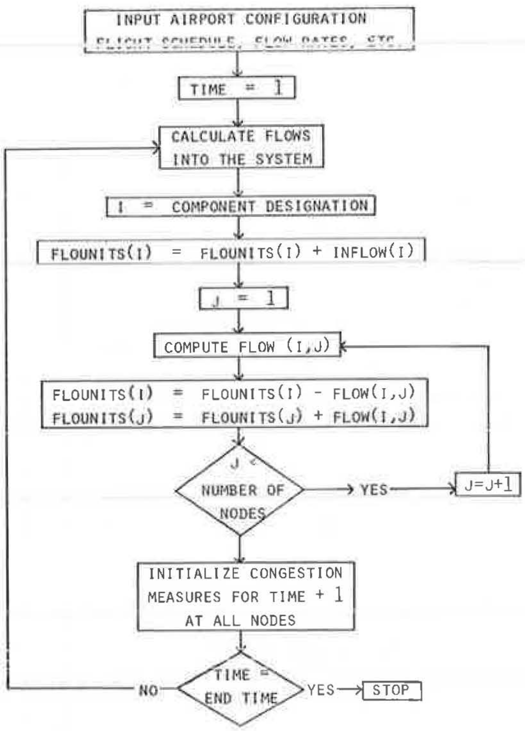


Figure 2. Calculation sequence of ACAP algorithm.

of service, definitions of the following terms are necessary:

1. Level-of-service measure—a physical measure of how a component subsystem or system performs, and
2. Level-of-service criterion—a specified maximum tolerable limit on the level-of-service measure.

The capacity of the airport system, as well as its subsystems and components, is a direct function of three concepts:

1. The level-of-service criteria for the system, subsystems, and components of the airport in question;
2. The period of time over which capacity is to be determined; and
3. The pattern of demand of passengers, aircraft, baggage, and ground vehicles for the airport in question.

The following definitions of airport capacity (designated ACAP) have been adopted for use in this study:

1. Airport system capacity—the maximum level of demand of a given pattern that can be imposed on an airport system in a given interval of time without violating any specified level-of-service criterion for the airport system as a whole for any of its subsystems or components,
2. Airport subsystem capacity—the maximum level of demand of a given pattern that can be imposed on a subsystem in a given interval of time without violating any specified level-of-service criterion for the particular subsystem or any of its components, and
3. Airport component capacity—the maximum level of demand of a given pattern that can be imposed on a component in a given interval of time without violating a specified level-of-service criterion for that component.

As defined above, a level-of-service measure is a physical measure of how a system or part of a system performs. But the opposite measure—level of congestion—is much easier to visualize and quantify. Level of congestion is defined as a measure of how poorly a system or a portion of a system performs. Thus, the more a level-of-congestion measure increases, the worse the system, subsystem, or component performs, and vice versa. In this paper, measures of congestion such as queue length and waiting time are used to denote system, subsystem, and component performance.

MODELING TECHNIQUES

To develop a computer program for modeling passenger and baggage flow within an airport terminal, a basic algorithm was established for the flow network and a series of submodels for various components in the terminal, e.g., ticket counters, security check, and lounge area. As mentioned previously, prior work in this area has been very limited because most of the development has been on the airside of the airport. Thus, we decided to either use previously developed models or develop mathematical models based on field observations.

The basic algorithm for the ACAP model is presented below, and two modeling procedures are demonstrated. One method is component modeling by the use of regression analysis of experimental observation; the other method is a conventional modeling process of mathematically describing experimental observations.

ACAP Algorithm

Since the number of people at a given component at any time is a function of the flow of people through preceding activities, a stagewise or recursive algorithm was selected as the most suitable means of modeling flow through an airport. Because of the complexity of many airports and the highly time-dependent nature of some passenger flows, a single steady-state description of the airport that applies for all times, or even for an interval of a few hours, was not possible. The arrival of passengers at a check-in is an example of a flow that varies dramatically with the flight schedule.

The algorithm adopted accomplishes two purposes: The first is to determine the change in the status of the demands at the various activities from one time interval to the next, and the second is to determine the congestion measures at each activity during the previous time interval. Reasonable time intervals for use in an analysis should be from 1 to 5 min.

The ACAP algorithm performs calculations in the following sequence, as shown in Figure 2.

1. Calculate the flows into the system during the next time interval from the groundside and from the airside on the basis of data input by the user. Increment the appropriate counters to indicate the increased numbers of units at all components affected by current flows.
2. Set I = 1.
3. Call a subroutine to calculate the flow from activity I to each activity J for which flow from activity I to activity J exists. Decrement the counter for component I to indicate this outflow.
4. Increment the counters for activities J to reflect the inflows that occur during the following time interval.
5. Test to determine if I is less than the total

number of components. If it is, increment I by one and go to step three; otherwise, go to step six.

6. Calculate the measures of congestion for each activity as a function of the flow to that activity during the following time interval, the service rate, the number of servers, and on to completion.

Because the capacity of an airport is affected by the number of users at the initial condition, it is usually suggested that the starting time for the calculations be midnight or early morning or some other time when the airport can be considered empty, except possibly for some long-term parking. These initial conditions, then, will have little or no effect on the calculations performed for the day or evening, when the capacity of the airport is most likely to be approached.

In its stepwise nature, the algorithm above, which is repeated once for each time interval for the period during the day to be analyzed, is reminiscent of simulation, but it differs from simulation in the following basic ways:

1. The method described above deals with network flows during discrete time intervals rather than stepping individuals through the airport and scheduling successive arrivals at all facilities for all persons as distinct events.

2. In the ACAP algorithm, the average waiting times and queue lengths during discrete time intervals are computed internally by using analytical models. In simulation, however, the exact number in each queue, transit, or service is tabulated continuously throughout the analysis period, and then the average measures of congestion are computed externally, on a strictly empirical basis, after the simulation is completed.

Because of these factors, the proposed method requires considerably less computer time than a simulation model would.

Component Modeling by Empirical Methods

The executive algorithm handles flows from node to node in a very general and computationally efficient way. Thus, each of the component models focuses on the activity at a particular node or type of node.

The executive algorithm handles the flows within discrete time steps, the durations of which are input by the user. At the beginning of a time step, at a given node, the present queue length Lq is known, as is the total number of people T who will desire service at that node during the time step. T, then, can be thought of as the number of people in the system at the beginning of the step plus new arrivals at the node during the step. The algorithm requires computation of (a) congestion measures at the end of the time interval and (b) the number of services during the interval.

In view of the fact that the user inputs the time step Δt, this quantity must be treated as a variable in the analysis.

The approach used for developing component models through regression analysis is illustrated below for the security check and the ticket counter to demonstrate the concepts.

Security Check

To treat the time step Δt as a variable, the data are grouped into successive time intervals with lengths that vary randomly from, say, 0.5 to 5 min. The data are then arranged as follows:

Lq_j = queue length at the beginning of the j th time interval,
T_j = number of people who desire service during the j th interval (Lq_j plus the number currently being served plus the number of arrivals during the interval),
$FOUT_j$ = number of services during the j th interval,
μ_j = average service rate during the j th interval, and
Δt_j = length of the j th interval.

Then the following regressions are performed on terminal observations:

$$\hat{Lq}_{j+1} = f(Lq_j, T_j, \mu_j, \Delta t_j) \tag{1}$$

$$\hat{FOUT}_j = g(Lq_j, T_j, \mu_j, \Delta t_j) \tag{2}$$

An estimate of Lq_{j+1} can be obtained from $\hat{FOUT}_j$:

$$S_{j+1} = T_j - FOUT_j \tag{3}$$

is the number in the system at the end of the j th time interval. Then,

$$Lq_{j+1} = \begin{cases} 0 & \text{if } S_{j+1} = 0 \\ S_{j+1} - 1 & \text{otherwise} \end{cases} \tag{4}$$

But an attempt to compute $FOUT_j$ in terms of $\hat{L}_{j+1}$ involves an ambiguity of one if $\hat{Lq}_{j+1} = 0$.

The treatment of μ_j requires additional consideration, since observations indicate that the service rate increases as the queue length increases. It is convenient, however, to use a constant overall service rate μ and allow the predictors Lq_j and T_j to account for increased numbers of services when there is congestion.

There are analytical methods for computing the average time spent in the queue as a function of queue length (10). However, the following is more consistent with the calculation of measures of congestion for a point in time and requires no assumptions regarding stationarity. As discussed previously, the queue length Lq at the end of an interval is calculated; thus, the time spent in a queue of this length is

$$\sum_{i=0}^{Lq-1} X_i \tag{5}$$

where X_i ($i = 1, 2, \ldots, Lq - 1$) = service time for other members of the queue who arrived earlier and X_0 = time required for the service currently being performed. But the mean of this sum is Lq/μ.

The fact that the current service may be partly completed when the Lq th person entered the queue has been disregarded above. The average waiting time Wq so obtained is the average waiting time that corresponds to a queue length of Lq, not the average waiting time during a period of time during the day. This calculation of Wq, moreover, involves no prior assumptions regarding probability distributions, services, or interarrival times; the only assumption is that the average service time is known. Whatever random properties are exhibited in the data, however, are reflected in Wq.

Ticket Counters and Check-In Stations

The check-in stations and ticket counters are modeled as discussed above, except that the number of servers must be treated as another variable. Thus, the following regression formats were developed:

$$Lq_{j+1} = f(Lq_j, T_j, \mu_j, C_j, \Delta t_j) \quad (6)$$

$$FOUT_j = g(Lq_j, T_j, \mu_j, C_j, \Delta t_j) \quad (7)$$

where C_j is the number of servers during the jth interval.

Empirical Limitations

A weakness of this approach is that the models developed are, strictly speaking, valid only for the airports for which data are included in the analysis or for other airports that are very similar to them. This problem was partially solved by collecting data from as diverse a set of circumstances as possible and including meaningful parameters in the regression models so as to allow the models to be adapted to a wide set of conditions.

It should also be noted that any approach to component modeling would involve either developing empirical models or using analytic queueing models on the basis of empirical validation. Thus, the only way to avoid the limitations of empiricism is to refrain from developing any models at all.

Intervening Activities Modeling

A method was used to include an "intervening activities" model in the airport capacity algorithm. This involved characterizing the intervening activities engaged in by airline passengers from an algorithmic standpoint and modeling the activity at the intervening activity nodes. The calculation of measures of congestion at intervening activities, which are less important than measures of congestion for essential activities, is a subject for future discussion. The algorithm deals with measures of congestion for essential activities.

Algorithmic Considerations

Technically, there is an opportunity for some sort of intervening activity (IA) by passengers between essentially any pair of nodes within an airport terminal building. Practically speaking, however, some points are much more likely to involve significant IA time than others. At some airports, for example, there is limited opportunity for intervening activities beyond the security check. Although one could go to an intervening activity before going to the ticket counter, it is reasonable to think that most people would go to the ticket counter—an essential activity that sometimes generates long queues and involves unpredictable waiting times—before engaging in unessential intervening activities. Thus, the single most likely point for significant IA time for people who have to buy tickets is between the ticket counter and the security check.

It is clear, however, that the most probable points for intervening activity are highly variable from airport to airport. It is reasonable, then, to allow the user to define the position of the major intervening activity nodes along with the rest of the airport configuration. It is anticipated that each path through the system will have at most two IA nodes, but this is not a constraint.

This approach for including intervening activities is very compatible with the executive algorithm that has been developed. Moreover, an approach that involved the modeling of intervening activities after each node would require much more core and execution time and would probably be less flexible than the suggested method.

Finally, it is more effective to handle intervening activities on a collective basis; that is, a given IA node can actually represent several separate activities, such as a restaurant, a gift shop, and a magazine stand that are all in the same area. Representing all of these activities as separate nodes would greatly increase core requirements and execution time, and it is doubtful that the additional modeling detail would yield significant useful information.

Component Modeling

At the beginning of a time step, the following information is available for any given IA node: (a) OCCUPY (L, I, IFL), or the number of units available to be serviced during the time step at node I, following path L, and destined to take flight IFL (the index IFL has an artificial meaning for deplaning units of flow); and (b) FLTIM (L, IFL), or the time of departure of flight number IFL, which is reachable through path L.

It was necessary to develop a mechanism for scheduling flows out of the IA nodes. To achieve this, a function f(t) was developed that gives the probability that a person in an intervening activity, who has available or excess time t before his or her flight, leaves the intervening activity during a time interval of length Δt.

Suppose, for path L and flight IFL, the available time at the beginning of the current time step is $\Delta t'$, which is not necessarily the same as Δt. The number of "service" completions at IA node I in one time step is given by

$$OCCUPY(L, I, IFL)\, f(t)(\Delta t'/\Delta t) \quad (8)$$

It has been assumed above that the probability of leaving the intervening activity is approximately constant during small intervals of time—say, up to 5 min. A single f function can thus be used for any reasonably small time step $\Delta t'$.

Next, the "available" time t must be calculated. The most obvious way to compute t is simply to form the difference between the flight departure time and the present time. This does not, however, take into account the inevitable path-to-path variations in the expected time required for necessary activities beyond the IA node. It was therefore decided that the user should input this expected required time following each IA node. The user can only make a rough estimate of the required time, of course, but this is exactly what a passenger would do in the process of deciding whether to engage in an intervening activity.

Time t, then, is

$$t = FLTIM(L, IFL) - T_1 - T(I) \quad (9)$$

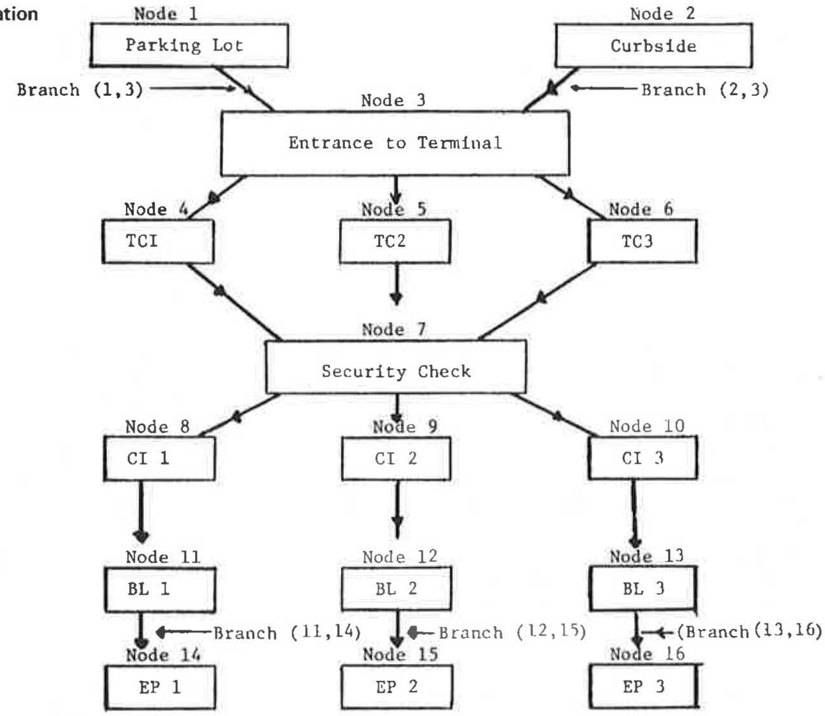
where T_1 is the current time and T(I) is the estimated required time for further required activities beyond IA node I.

The development of the f function must be in discrete tabulated form: $f(t_i)$ $(i = 1, 2, \ldots, n)$, where $f(t_i)$ is the probability that a person in an intervening activity, who has available time equal to t_i, will leave the activity within a time interval of length Δt, the step size for the t_i array. The value of Δt is considered to be on the order of 2-5 min.

ACAP1 COMPUTER PROGRAM

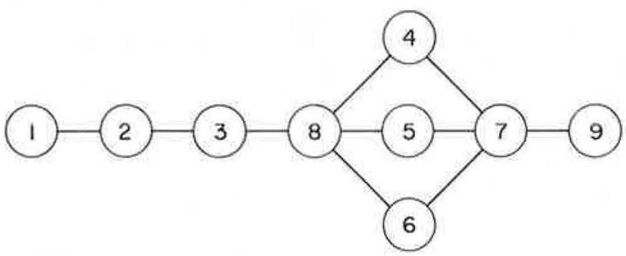
It is not possible to present all of the input in the ACAP1

Figure 3. Enplaning portion of airport transportation network.



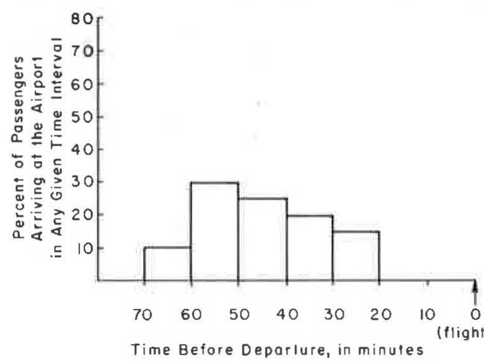
TC = Ticket Counter and baggage check
CI = Check in Counter
BL = Boarding Lounge
EP = Enplaning Area

Figure 4. Path-to-sequence transformation.



PATHS	SEQUENCE IN COMMON	PATH REWRITTEN USING SEQUENCES
1,2,3,8,4,7,9	(1) 1,2,3,8	(1),(2),(5)
1,2,3,8,5,7,9	(2) 4	(1),(3),(5)
1,2,3,8,6,7,9	(3) 5	(1),(4),(5)
	(4) 6	
	(5) 7,9	

Figure 5. Distribution of passenger arrivals by intervals.



program, but a brief overview is given to demonstrate the concepts.

Description of the Program

The ACAP1 program was written in FORTRAN IV computer language for use with the CDC 6600/6400 computer system at the University of Texas at Austin. However, it is written in a form that should be relatively easy to use with other computer systems.

Since the program analyzes the flow of passengers through an airport system that has a given demand, as a function of time, the configuration of the airport is a required input to the computer program. The program is structured so that an airport design or subsystem design of any configuration or layout can be input by the user. It should also be noted that congestion caused by flows from outside a particular subsystem under consideration can be handled. Inputs from outside the system, such as the time-varying arrivals of passengers, are also defined by the user as input to the program.

It should be noted here that ACAP1 was developed as a preliminary program to test the overall algorithm. It was designed in modular form to permit the addition and deletion of individual component models as new component models are developed or existing models are updated, without affecting the overall algorithm. In fact, new component models are currently being developed and implemented into the program as part of the continuing ACAP research.

Conceptual Description of Input

It may appear at first glance that the input to this program model is somewhat intricate, but the generality of use as well as the accuracy of the program requires complicated input so that the program will be applicable to the wide variety of shapes, sizes, and configurations of either existing or planned airports.

Input of the Airport Configuration

An airport can be viewed as a transportation network. By defining the nodes of the network and the branches between nodes, the user can define any airport configuration. Consider, for example, the very simple case shown in Figure 2. The enplaning part of the system will be used to demonstrate the concepts. The required input would include (a) the number of nodes, (b) the activity type of each node, and (c) the sequence of nodes.

The number of nodes is equal to the total number of separate individual nodes. In the example shown in Figure 3, the number of nodes is equal to 16. Note that it is possible, in fact probable, to have more than 1 node of a particular type; for example, in Figure 3 there are 3 ticket-counter nodes.

The activity type of each node, although seemingly insignificant, is indeed critical. The program selects the specific model for use in computing the capacity of that node based on the type of activity that occurs at that node.

As mentioned above, the user-defined airport configuration is based on the network concept. In this concept, all components in the system (such as ticket counters, security checks, boarding lounges, and baggage claims) and paths through the system are represented by a series of nodes and links. There are two approaches to inputting the configuration of the system into the model. One approach is to input all paths through the system or subsystem with each node in sequence, as shown in Figure 4. This method, although simple, is very cumbersome. The second approach is slightly more complicated, but its primary advantage is that it drastically reduces the number of calculations, thereby reducing program running time and thus cost. In this method, the layout is first examined and the paths are categorized by the sequences they have in common. The paths are then input as a series of common sequences of nodes rather than a series of nodes. This transformation from paths constructed of nodes to paths constructed of sequences is demonstrated in Figure 4.

Input of Flows to the System

As mentioned above, the external flows of passengers to the system or subsystem must be input by the user. It was assumed that passengers arrive at the system or subsystem boundary according to an unspecified defined distribution that has one end at or near the flight departure time. This distribution can approximate a uniform, a normal, or some other known distribution. The arrival distribution is considered to be made up of the time differences between the departure time of the flight and the times at which the passengers arrive at the airport for the flight. If the distribution is divided into small time intervals, the arrival rate can be assumed to be constant over these intervals. For example, the arrival distribution curve shown in Figure 5 is divided into smaller time intervals over which the arrival rate is considered to be constant. Then the ending time of each of the smaller intervals and the constant arrival rates are input for each flight on each path.

Figure 6. Plan view of Hobby Airport terminal building.

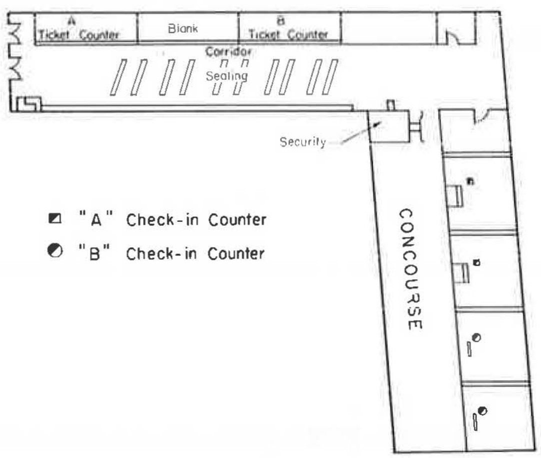


Figure 7. Input data for node characteristics.

AIRPORT SAMPLE PROBLEM NOV 18 1976

NETWORK PARAMETERS

NUMBER OF NODES = 10 NUMBER OF NODE SEQUENCES = 9 NUMBER OF PATHS = 8 SUMMARY TABLE TIME INTERVAL = 30 MIN

BEGINNING TIME = 6:00:00 ENDING TIME = 22:30:00 TIME STEP = 1.00 MIN NUMBER OF STEPS = 990 PRINT SAMPLE RATE = 60

ALL NODES WERE INITILIZED TO ZERO

NODE CHARACTERISTICS

NODE NUMBER	COMPONENT LABEL	MODEL NUMBER	AVG SERVICE RATE PER MIN	NUMBER OF SERVERS	MAX ALLOWABLE AVG QUEUE LENGTH	MAX ALLOWABLE AVG WAITING TIME(MIN)
1	TERM ENTR	2	20.00	2	4.00	.33
2	A TKT CTR	2	.60	4	8.00	15.00
3	B TKT CTR	2	.60	2	6.00	15.00
4	CORRIDOR	2	20.00	4	5.00	.50
5	SECURITY	2	5.00	1	20.00	5.00
6	CONCOURSE	2	20.00	6	2.00	.50
7	A CHECKIN1	2	2.50	1	15.00	6.00
8	A CHECKIN2	2	2.50	1	15.00	6.00
9	B CHECKIN1	2	2.50	1	15.00	6.00
10	B CHECKIN2	2	2.50	1	15.00	6.00

Figure 8. Input data for network characteristics.

NETWORK CHARACTERISTICS

** PATHS SHARING EACH NODE SEQUENCE **

NODE SEQUENCE NUMBER								
1	1	2	3	4	5	6	7	8
2	1	2						
3	3	4						
4	1	2	3	4	5	6	7	8
5	1	2	3	4	5	6	7	8
6	1	5						
7	2	6						
8	3	7						
9	4	8						

** NODES IN EACH SEQUENCE **

NODE SEQUENCE NUMBER		
1	1	
2	2	
3	3	
4	4	
5	5	6
6	7	
7	8	
8	9	
9	10	

** NODES SUCCEEDING SEQUENCE K FOLLOWING PATH L **

NODE SEQUENCE NUMBER K	PATH NUMBER L	SUCCEEDING NODE
1	1	2
1	2	2
1	3	4
1	4	4
1	5	4
1	6	4
1	7	4
1	8	4
2	1	4
2	2	4
3	3	5
3	4	5
4	1	5
4	2	5
4	3	3
4	4	3
4	5	5
4	6	5
4	7	5
4	8	5
5	1	7
5	2	8
5	3	9
5	4	10
5	5	7
5	6	8
5	7	9
5	8	10
6	1	-1
6	5	-1
7	2	-1
7	6	-1
8	3	-1
8	7	-1
9	4	-1
9	8	-1

** BEGINNING NODES FOR EACH PATH **

PATH	NODE
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1

APPLICATIONS

This program can be a valuable tool for making estimates of airport capacities for use by airport planning and design consultants, airport administrators, and other interested persons. It has application both to the analysis of existing airport components and the prediction of the capacities of components of future airports. The applications take two basic forms: (a) identification and specification of research and capital improvement priorities for various components of the airport system and (b) preliminary testing of alternate designs and sizing components so that individual capacities are adequate to meet projected demand and at the same time are balanced with the capacities of other components.

Since the measures of congestion are calculated for each time step at each component, it is possible to determine whether minimally acceptable service criteria are met at each component. Thus, if, at any time during the daily operation of the airport or candidate design of an airport, the measures of congestion become excessive at any component, the program then prints out a list of the components, the times at which the violations occurred, and the type of offending measure of congestion. The criteria for determining when a measure of congestion is "excessive" are specified in the input by the user. This type of output permits the user to analyze the sensitivity of these level-of-service measures of the airport by changing the flight schedule or available components, inputting the changes, performing another run, and analyzing the output. Thus, to examine the level-of-service effects of adding a second channel for

Figure 9. Input rates.

CONSTANT INPUT RATES

PATH NUMBER	RATE NUMBER	ENDING TIME OF RATE INTERVAL	INPUT RATE PER MIN
1	1	6:30:00	2.90
1	2	7:00:00	.01
1	3	7:30:00	3.00
1	4	8:00:00	.02
1	5	8:30:00	3.20
1	6	10:30:00	.01
1	7	11:30:00	3.00
1	8	12:30:00	.02
1	9	13:00:00	2.20
1	10	13:30:00	.01
1	11	14:00:00	2.20
1	12	14:30:00	.01
1	13	15:00:00	2.10
1	14	6:00:00	.01
1	15	16:00:00	2.00
1	16	16:30:00	.01
1	17	17:00:00	1.40
1	18	18:00:00	.01
1	19	18:30:00	.70
1	20	19:00:00	.01
1	21	19:30:00	.60
1	22	20:30:00	.01
1	23	21:00:00	.50
1	24	21:30:00	.01
1	25	22:30:00	0
2	1	6:30:00	.04
2	2	7:00:00	3.00
2	3	7:30:00	.05
2	4	8:00:00	3.10
2	5	8:30:00	.04
2	6	9:00:00	2.90
2	7	9:30:00	.10
2	8	10:00:00	2.50
2	9	10:30:00	.10
2	10	11:00:00	2.30
2	11	6:00:00	.10
2	12	12:00:00	2.10
2	13	13:30:00	.10
2	14	6:00:00	1.80
2	15	15:00:00	.08
2	16	15:30:00	2.50
2	17	16:00:00	.02
2	18	16:30:00	2.20
2	19	17:30:00	.03
2	20	18:00:00	1.90
2	21	18:30:00	.01
2	22	19:00:00	1.10
2	23	19:30:00	.01
2	24	20:00:00	.86
2	25	20:30:00	.02
2	26	22:30:00	0
3	1	6:30:00	.70
3	2	11:25:00	.01
3	3	11:55:00	3.20
3	4	18:00:00	0

CONSTANT INPUT RATES

PATH NUMBER	RATE NUMBER	ENDING TIME OF RATE INTERVAL	INPUT RATE PER MIN
3	5	18:30:00	2.60
3	6	22:30:00	0
4	1	8:45:00	0
4	2	9:15:00	3.40
4	3	15:10:00	.01
4	4	15:40:00	2.86
4	5	22:30:00	0
5	1	6:30:00	.40
5	2	7:00:00	.01
5	3	7:30:00	.50
5	4	8:00:00	.01
5	5	8:30:00	.60
5	6	10:30:00	.01
5	7	11:30:00	.20
5	8	12:30:00	.01
5	9	13:00:00	.17
5	10	13:30:00	.01
5	11	6:00:00	.15
5	12	14:30:00	.01
5	13	15:00:00	.13
5	14	15:30:00	.01
5	15	16:00:00	.10
5	16	6:00:00	.01
5	17	17:00:00	.08
5	18	18:00:00	.01
5	19	18:30:00	.05
5	20	19:00:00	.01
5	21	19:30:00	.03
5	22	20:30:00	.01
5	23	21:00:00	.03
5	24	21:30:00	.01
5	25	22:30:00	0
6	1	6:30:00	.01
6	2	7:00:00	.50
6	3	7:30:00	.01
6	4	8:00:00	.60
6	5	8:30:00	.01
6	6	9:00:00	.40
6	7	9:30:00	.02
6	8	10:00:00	.30
6	9	10:30:00	.01
6	10	11:00:00	.25
6	11	6:00:00	.01
6	12	12:00:00	.18
6	13	13:30:00	.01
6	14	14:00:00	.14
6	15	15:00:00	.01
6	16	6:00:00	.17
6	17	16:00:00	.01
6	18	16:30:00	.16
6	19	17:30:00	.01
6	20	18:00:00	.08
6	21	18:30:00	0
6	22	19:00:00	.04
6	23	19:30:00	.01

security checking, for example, the user would perform two runs of the program. The first run would have only one channel for security check whereas the second run would include two. The effect of two channels could be determined by analyzing the results for the two runs. This type of analysis would be useful in determining whether an existing airport is adequate for meeting future demand and, if not, in identifying the areas in need of expansion. In the case of a planned airport, the user would be able to determine whether a design under consideration is suitable for demands projected during the design life.

SAMPLE PROBLEM

The use of the concepts presented above is perhaps best demonstrated through the presentation of the solution of an example problem by use of ACAP1. The example is a relatively simple, hypothetical one used only for illustrative purposes. The example is designed to resemble flows of enplaning passengers within the terminal building at Hobby Airport in Houston, Texas, and illustrates that, although the inputs are extensive, they do not place an unreasonable burden on the user.

The Hobby Airport was selected primarily because it is of rather simple design. The airport serves primarily as a relief airport for Houston Intercontinental Airport. The commercial traffic is composed of intrastate commuter service and connecting service to the Dallas-Fort Worth area. A plan view of the terminal building is shown in Figure 6.

The input data for this problem are shown in echo-print form in Figures 7-9. The echo print is used because of the labeling, which makes the problem input easier to understand.

In the construction of the input data deck, several steps must be taken. The first step is to designate the bounds of the analysis period. As mentioned previously, a beginning time should be selected so that the airport can be considered empty. For the example problem, 6:00 a.m. and 10:30 p.m. were chosen as the beginning and end of the analysis period, respectively.

The second step is to delineate the airport configuration in terms of a node-link network. Each component of the system or subsystem is considered to be a node. Thus, each of the ticket counters and each of the checkpoints (Figure 6) is treated as a separate node. Each node is then arbitrarily assigned a node number. The node number, node label, model number, measures of congestion, and number of available servers and their service rates for each node are all required input. The links of the node-link network are implied in the path-sequence construction discussed above, which is also a required input.

The final step in assembling the information for the input deck is the inclusion of the arrival-flow distributions. This is accomplished by examining the distributions relative to the flight schedule on each path in a manner similar to that described above.

As Figure 7 shows, there are four servers at the ticket counter of airline A and only two servers at the ticket counter of airline B. Airline A has five times as many flights as airline B at this airport. In addition, note that there are four servers and six servers at the corridor and concourse components, respectively, because it is assumed that as a result of layout constraints only those numbers of people can, at any given time, pass abreast a given imaginary line that crosses those components. The figure shows that the time interval selected was 1 min.

Figure 8 shows the network information, such as which nodes are in each sequence and which nodes follow which sequence. For example, for path 1, nodes 1, 2, 4, 5, and 6 are included, whereas for path 6, only nodes 1, 4, 5, and 7 are included. In the section that contains the succeeding nodes, the negative numbers indicate the end of a path.

Figure 9 shows the constant input rates chosen for this example based on the flight schedule shown in Table 1. These input rates are assumed to be relatively low on all paths except for a period 30-60 min prior to the scheduled departure time of a flight on that path. Thus, on path 2, the fourth input rate is a constant 3.10 passengers/min for the time interval from 7:30 to 8:00 a.m. In addition, note that the input rate on all paths between the last flight departure time on a path and the closing time of the airport or the end of the period under consideration has been set to zero.

The program then calculates the flows into and out of

Table 1. Departures from Hobby Airport.

Airline	Flight Destination	Departure Times
A	Dallas Love Field	7:00, 7:30, 8:30, 9:30, 10:30, and 11:30 a.m.; 12:30, 1:30, 2:30, 3:30, 4:30, 5:30, 6:30, 7:30, 8:30, and 9:30 p.m.
	San Antonio	8:00 a.m.; 12:00 noon; 4:00 and 8:00 p.m.
	Harlingen	9:00 and 11:30 a.m.; 2:30, 5:00, and 7:00 p.m.
B	Dallas-Fort Worth	7:00 and 9:45 a.m.; 12:25, 4:10, and 7:00 p.m.

Figure 10. Calculation of passenger flows for one time step.

** NODE CONDITIONS FOR TIME STEP 101 FROM 9:00:00 TO 9:01:00 **

NODE NUMBER	COMPONENT LABEL	INFLOW RATE PER MIN	TOTAL OUTFLOW	AVG WAITING TIME(MIN)	AVERAGE QUEUE LENGTH	MAX AVG WAITING TIME ALLOWED	MAX AVG WAITING TIME EXCEEDED	MAX AVG QUEUE LENGTH ALLOWED	MAX AVG QUEUE LENGTH EXCEEDED
1	TERM ENTR	4.1	7.2	4.56E-02	1.02E+00	.33	NO	4.00	NO
2	A TKT CTR	2.9	2.4	1.19E+01	2.86E+01	15.00	NO	8.00	YES
3	B TKT CTR	3.4	1.2	1.21E+01	1.45E+01	15.00	NO	6.00	YES
4	CORRIDOR	6.7	6.7	8.53E-03	6.02E-01	.50	NO	3.00	NO
5	SECURITY	4.5	4.5	7.40E-01	3.52E+00	5.00	NO	20.00	NO
6	CONCOURSE	4.5	4.5	0	0	.50	NO	2.00	NO
7	A CHECKIN1	.9	.9	0	0	6.00	NO	15.00	NO
8	A CHECKIN2	1.9	1.9	3.66E-01	9.15E-01	6.00	NO	15.00	NO
9	B CHECKIN1	.0	.0	0	0	6.00	NO	15.00	NO
10	B CHECKIN2	1.7	1.7	2.79E-01	6.96E-01	6.00	NO	15.00	NO

** FLOW INTO EACH NODE ALONG EACH PATH DURING THE TIME STEP **

NODE NUMBER	TOTAL FLOW	PATH NUMBER 1	2	3	4	5	6	7	8
1	4.1	.0	.1	.0	3.4	.0	.0	.0	.5
2	2.9	.0	2.9	0	0	0	0	0	0
3	3.4	0	0	.0	3.4	0	0	0	0
4	6.7	.8	1.6	.0	3.4	.0	.4	.0	.5
5	4.5	.8	1.6	.0	1.2	.0	.4	.0	.5
6	4.5	.9	1.5	.0	1.2	.0	.4	.0	.5
7	.9	.9	0	0	0	.0	0	0	0
8	1.9	0	1.5	0	0	0	.4	0	0
9	.0	0	0	.0	0	0	0	.0	0
10	1.7	0	0	0	1.2	0	0	0	.5

** NUMBER OF UNITS FOLLOWING EACH PATH REMAINING AT EACH NODE AT THE END OF THE TIME STEP **

NODE NUMBER	TOTAL UNITS	PATH NUMBER 1	2	3	4	5	6	7	8
1	4.1	.0	.1	.0	3.4	.0	.0	.0	.5
2	118.5	39.1	79.4	0	0	0	0	0	0
3	32.1	0	0	.1	32.0	0	0	0	0
4	6.7	.8	1.6	.0	3.4	.0	.4	.0	.5
5	4.5	.8	1.6	.0	1.2	.0	.4	.0	.5
6	4.5	.9	1.5	.0	1.2	.0	.4	.0	.5
7	.9	.9	0	0	0	.0	0	0	0
8	1.9	0	1.5	0	0	0	.4	0	0
9	.0	0	0	.0	0	0	0	.0	0
10	1.7	0	0	0	1.2	0	0	0	.5

** CURRENT CONSTANT INPUT RATES **

PATH NUMBER	RATE NUMBER	INPUT RATE PER MIN
1	6	.01
2	7	.10
3	2	.01
4	2	3.40
5	6	.01
6	7	.02
7	2	.01
8	2	.50

each component and the associated measures of congestion at each component for each time step throughout the period being examined. As Figure 10 shows, the results of these calculations are printed for the individual time steps at a sample rate to be determined by the user. Figure 7 shows that the results are printed once for every 60 time steps.

At the end of each run, a final summary is presented that shows when and where the congestion criteria have been exceeded. As can be seen in Figure 11, the congestion appears to be concentrated at the ticket counters, the most congestion at the counter of airline B. Since airline B has only two agents at this component, it would appear that more agents are needed. Two addi-

Figure 11. Final summary with two servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
	3	B TKT CTR	0	0	23.3	4.10E+00
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	86.7	7.70E+00	100.0	1.98E+01
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.84E+00
	3	B TKT CTR	40.0	2.95E+00	100.0	1.02E+01
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
	3	B TKT CTR	0	0	6.7	7.90E-01
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
	3	B TKT CTR	50.0	5.62E+00	90.0	1.29E+01
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
	3	B TKT CTR	56.7	4.09E+00	100.0	1.30E+01
12:30:00 TO 13:00:00	3	B TKT CTR	0	0	23.3	2.03E+00
15:00:00 TO 15:30:00	3	B TKT CTR	0	0	33.3	4.39E+00
15:30:00 TO 16:00:00	3	B TKT CTR	63.3	2.66E+00	100.0	1.33E+01
16:00:00 TO 16:30:00	3	B TKT CTR	0	0	43.3	3.80E+00
18:00:00 TO 18:30:00	3	B TKT CTR	6.7	4.17E-01	63.3	6.55E+00
18:30:00 TO 19:00:00	3	B TKT CTR	20.0	1.31E+00	86.7	7.90E+00

Figure 12. Final summary with three servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

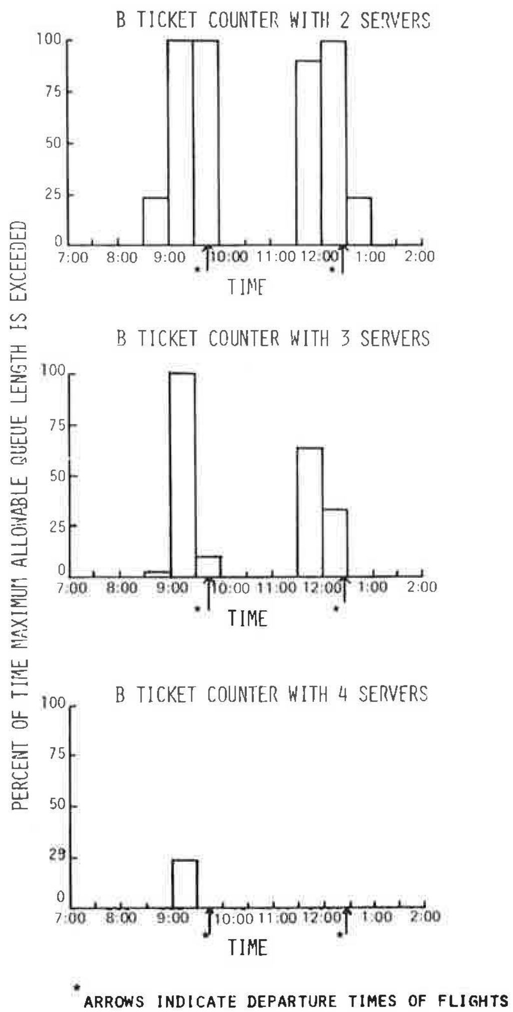
			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
	3	B TKT CTR	0	0	3.3	3.08E-01
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	0	0	100.0	5.44E+00
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.84E+00
	3	B TKT CTR	0	0	10.0	1.10E+00
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
	3	B TKT CTR	0	0	63.3	4.39E+00
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
	3	B TKT CTR	0	0	33.3	2.93E+00
15:30:00 TO 16:00:00	3	B TKT CTR	0	0	63.3	2.09E+00
18:00:00 TO 18:30:00	3	B TKT CTR	0	0	13.3	5.33E-01
18:30:00 TO 19:00:00	3	B TKT CTR	0	0	16.7	9.53E-01

Figure 13. Final summary with four servers at ticket counter of airline B.

** SUMMARY OF OVER-CONGESTED NODE CONDITIONS **

			MAX ALLOWABLE AVG WAITING TIME		MAX ALLOWABLE AVG QUEUE LENGTH	
TIME INTERVAL	NODE NUMBER	COMPONENT LABEL	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS	PERCENTAGE OF TIME EXCEEDED	AVG DEVIATION IN EXCESS
7:00:00 TO 7:30:00	2	A TKT CTR	0	0	100.0	2.50E+00
7:30:00 TO 8:00:00	2	A TKT CTR	0	0	100.0	7.62E+00
8:00:00 TO 8:30:00	2	A TKT CTR	0	0	100.0	1.34E+01
8:30:00 TO 9:00:00	2	A TKT CTR	0	0	100.0	1.86E+01
9:00:00 TO 9:30:00	2	A TKT CTR	0	0	100.0	1.26E+01
	3	B TKT CTR	0	0	23.3	5.54E-01
9:30:00 TO 10:00:00	2	A TKT CTR	0	0	100.0	3.80E+00
10:00:00 TO 10:30:00	2	A TKT CTR	0	0	26.7	2.52E+00
10:30:00 TO 11:00:00	2	A TKT CTR	0	0	56.7	6.46E+00
11:00:00 TO 11:30:00	2	A TKT CTR	0	0	100.0	1.54E+01
11:30:00 TO 12:00:00	2	A TKT CTR	0	0	100.0	9.51E+00
12:00:00 TO 12:30:00	2	A TKT CTR	0	0	3.3	2.97E-01
15:30:00 TO 16:00:00	10	B CHECKIN2	43.3	7.18E-01	43.3	1.79E+00
18:00:00 TO 18:30:00	9	B CHECKIN1	20.0	7.60E-01	20.0	1.90E+00
18:30:00 TO 19:00:00	9	B CHECKIN1	33.3	2.11E+00	33.3	5.28E+00

Figure 14. Percentage of time maximum allowable average queue length exceeded versus time of day.



tional runs of the program were made, and each time the number of servers at this component was incremented by one and all other input values were kept at the same level. Figures 12 and 13 show that a marked decrease in the amount of congestion at this component occurs with each additional server. A clearer view of this decrease in congestion can be seen in Figure 14, in which the percentage of time the maximum allowable queue length is exceeded is plotted versus time and the flight departure times are indicated by arrows on the time axis. As the plot for two servers shows, the congestion is so great that at times the queues do not dissipate until after the scheduled departure time of the aircraft. This problem is at least partially cured by the addition of an agent.

There is, however, a limit to the number of servers that can be added above which nothing is really gained. Notice in Figure 14 that, when four servers are used, the percentage of time the maximum allowable average queue length is exceeded is zero except for the interval between 9:00 and 9:30 a.m., but in Figure 11 the use of four servers produces a combined service rate so great that the queue length at the check-in counters becomes excessive. If each passenger is to be served adequately throughout the airport, additional servers must be provided at the check-in counters of airline B.

SUMMARY

This paper presents an introduction to a computer program that is designed to be a decision-making tool for use in airport capacity analysis and planning. The program has the flexibility to be used for either existing airports or planned airports of any configuration. The inputs to the program include the airport configuration, the flows into the system, and a description of the components that make up the system. This description of components includes measures of congestion and the number and service rate of servers.

The output of the program contains an echo print of all of the input data, a sample of the calculations for each time step, and a summary of when, where, and by how much each of the specified measures of congestion was violated. This type of output enables the user to determine the effect of using different methods of operation to eliminate the violations; these methods include adding more servers to the components at which the violations occur and rearranging the flight schedule to eliminate congestion by shifting the passenger flow in time. By reducing or eliminating the number and/or frequency of violations of measures of congestion, the capacity of the airport is increased.

The program is currently being revised and updated as new component models are developed. The revised version should be ready for publication in the near future.

ACKNOWLEDGMENT

This paper is based on a research study sponsored by the Office of University Research of the U.S. Department of Transportation through the Council for Advanced Transportation Studies at the University of Texas at Austin.

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. N. D. F. Gualda, B. F. McCullough, and W. J. Dunlay. Modeling the Airport Terminal Building for Capacity Evaluation Under Level-of-Service Criteria. Council for Advanced Transportation Studies, Univ. of Texas at Austin, Res. Rept. 57, Aug. 1978.
2. T. R. Chmores and B. F. McCullough. An Analysis of Passenger Processing Characteristics in Airport Terminal Buildings. Council for Advanced Transportation Studies, Univ. of Texas at Austin, Res. Rept. 58, Aug. 1978.
3. C.-H. Park and W. J. Dunlay, Jr. A Tandem-Queue Algorithm for Evaluating Overall Airport Capacity. Council for Advanced Transportation Studies, Univ. of Texas at Austin, Res. Rept. 44, draft, Feb. 1977.
4. E. V. Chambers and B. F. McCullough. A User's Manual for the ACAP Model for Airport Terminal Building Capacity Analysis. Council for Advanced Transportation Studies, Univ. of Texas at Austin, Aug. 1978.
5. K. W. Heathington and D. H. Jones. Identification of Levels of Service and Capacity of Airport Landside Elements. In Airport Landside Capacity, TRB, Special Rept. 159, 1975, pp. 72-91.
6. P. H. Beinhaker. Primer for Analysis of Airport

Landside Capacity. In Airport Landside Capacity, TRB, Special Rept. 159, 1975, pp. 17-34.
7. L.G. Klingen. Methods to Increase Landside Capacity at Existing Airports. In Airport Landside Capacity, TRB, Special Rept. 159, 1975, pp. 249-255.
8. R.E. Hom and J.C. Orman. Airport Airside and Landside Interaction. In Airport Landside Capacity, TRB, Special Rept. 159, 1975, pp. 196-208.
9. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
10. H.A. Taha. Operations Research. Macmillan, New York, 1972.

Publication of this paper sponsored by Committee on Airport Landside Operations.

Guidelines for Evaluating Characteristics of Airport Landside Vehicle and Pedestrian Traffic

F. LaMagna, P. B. Mandle, and E. M. Whitlock, Wilbur Smith and Associates, New Haven, Connecticut

Results of a study of the characteristics of landside vehicle and pedestrian traffic at Miami International, Stapleton International, and LaGuardia Airports and one terminal at John F. Kennedy International Airport are presented. Vehicle and pedestrian flow rates at all terminal buildings, curbside areas, parking facilities, and airport entrance and exit roadways were measured simultaneously and related to levels of air-passenger activity by using enplanements and deplanements as indices. Processing time and service rates were also sampled at several locations at three of the four airports. These data were obtained at ticket counters, automobile-rental areas, passenger security checkpoints, parking cashier operations, and other locations within the terminals. Representative per-passenger flow rates and processing times for pedestrians and vehicles are presented as rules of thumb to assist other airport planners.

Many agencies and organizations are attempting to analyze and derive solutions for the congestion problems encountered on the ground at airports, specifically on access roads and at terminal buildings. This paper results from several studies prepared for two organizations—the Transportation Systems Center of the U.S. Department of Transportation (1) and American Airlines (2, 3)—both of which are interested in airport congestion problems but from different viewpoints. Since the studies were designed to meet the distinctive needs of each organization, there were variations between them in the methods of data collection and the analyses performed.

Data were collected at four airports that represent, in total passenger enplanements, a cross section of the 20 largest airports in the United States. In 1978, John F. Kennedy International and LaGuardia Airports in New York, Stapleton International Airport in Denver, and Miami International Airport ranked fourth, seventh, eighth, and ninth, respectively, among U.S. airports in terms of total annual enplanements served. Data collected at John F. Kennedy International focused on the curbside area and access roads that serve the American Airlines terminal. At the other three airports, data were collected at each area of the airport where a passenger might encounter delays before boarding or after disembarking from an aircraft. This included all public areas in the terminal building, road curbside areas, and parking facilities. The data collected in those four studies form the basis for the guidelines and characteristics presented in this paper.

PURPOSE AND SCOPE

The purpose of this paper is to provide the airport planner and other interested groups with basic general guidelines for evaluating the reasonableness of vehicle and pedestrian forecasts for various sectors of the airport landside system and to present observed distributions of process times that can be used to plan passenger service facilities for airport terminal buildings. The findings presented relate to groundside vehicle characteristics, such as modal choice, traffic generation rates on airport roads and at parking facilities, and use of curb-frontage roadways; pedestrian trip-generation rates for airline passengers and visitors; and processing or service times for ticketing, security, and parking-cashiering operations at the subject airports.

AIRPORT CHARACTERISTICS

During 1979, Miami International Airport (MIA) handled about 8 248 000 enplaning passengers. MIA, which serves Dade County, Florida, is a major entry point for passengers arriving from South and Central America. During the study period (March 17 and 18, 1978), tourist traffic made up the largest portion of passenger demand. The proximity of Miami Beach and the cruise ships that berth at Miami generates a large portion of the tourist traffic. More than 25 percent of all enplaning air passengers are transfer passengers who do not have an impact on the terminal roadway system.

MIA provides more than 6000 public parking spaces, including 4700 spaces in the central terminal area in three garages and a surface lot. The terminal complex is on two levels and has approximately 1060 m (3500 ft) of arrival curb space and 1135 m (3750 ft) of departure curb space. A central island that has a dual curb separates the six-lane curbside roadways.

Stapleton International Airport (DEN) serves the Denver region and the largest volume of passengers of any airport between Chicago and the Pacific Coast. In 1978, DEN, which is classified as a major hub airport by the