SIMULATION METHODS FOR AIRPORT FACILITIES

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Air transportation has dramatically reduced long-distance travel time. Airline passengers can now travel from the east coast to California in 5 hours air time. However, further reduction in total travel time is hampered by airport delays that may be comparable to air travel time. Thus, reduction of airport delays must be achieved to attain additional savings in overall travel time as well as to provide dollar savings and other tangible and intangible benefits.

These travel delays are, for the most part, due to airport landside congestion. For the purposes of this paper, the airport is defined as that airport activity between the airport boundary and the arrival-departure gates. The problem has received considerable attention in recent years since, according to the Federal Aviation Administration, landside airport congestion appears to represent "the ultimate limitation to the growth" of many of the nation's largest airports (1). This has encouraged research on the various airport parameters that influence airport landside capacity and exploration of techniques to increase the effective operational capacity of existing airports. Figure 1 (9) shows the airport landside capital funding and the extent of the airport landside and its relation to various access modes. Access to the boundary often contributes to the congestion problem. However, bounding the airport landside problem to intra-airport operations is felt to be an accurate representation.

The most realistic method of quantitatively approaching airport landside traffic problems appears to be computer simulation of airport landside traffic flows. This paper describes how the simulation of the landside portion of an airport complex can be used to represent or model the airport landside system to accurately

determine the flow and holding capacity and the associated delays of the airport landside.

DEFINITION OF PROBLEM

The airport system complex must be viewed in terms of the total transportation system. Its primary purpose is to transfer a passenger from the ground transportation system to the air transportation system (and vice-versa) or to transfer a passenger from one portion of the air transportation system to another. It is basically an interface between ground travel and air travel.

The airport consists of 3 subsystems: (a) airspace portion of airports (including runways), (b) airside portion of airports (runway turnoffs and airline gates), and (c) landside portion of airports (everything from the airplane gate to the airport boundary). This paper, however, is concerned strictly with the landside portion of airport complexes. The controlling parameters for all landside operations are aircraft movements. The airline flight schedule, therefore, orders almost all activities within the airport boundaries. Based on aircraft class, flight schedule, and loading factors, the passenger demand on the landside facilities can be calculated.

The airport landside system can be viewed as a set of facilities designed to expeditiously deal with all airport landside traffic. A facility is a portion of the airport landside system where some function is performed. Similarly, a subfacility is a portion of a facility concerned with some subactivity. The landside traffic can be divided into 3 categories: people, baggage, and cargo (including mail). Landside facilities are of 3 types: ingress-egress, processing, and concession-amenity. The following list gives the typical facilities of each of these types.

Ingress-egress facilities
- Airport road system
- Rapid transit system
- Parking lot and parking spaces
- Sidewalks
- Corridors-guideway
- Baggage and cargo-moving equipment
- Terminal building
- Passenger facility (lobby and waiting rooms)
- Cargo storage facility

Processing facilities
- Ticket counters
- Security
- Boarding area
- Baggage check-in

Concession-amenity facilities
- Gift shops
- Lunch shops
- Restaurants
- Barber shops
- Lavatories

Typically, the airport population includes air passengers, employees of the airport complex, and airport visitors. Air passengers essentially represent the independent variable that governs all airport activities directly or indirectly. Air passenger demand significantly fluctuates as a function of hour of the day, day of the week, or month of the year. Also, the air passenger is frequently not the largest element of the total airport population. For example, a greater demand is often placed on the landside system by visitors and employees than by air travelers. Employees working at the airport

also place a significant load on the airport landside complex, especially in vehicle loads imposed on the ingress-egress system, which tends to correspond to passenger and visitor loads. Visitors include those that are passenger related and all others, e.g., sightseers and service people.

It is difficult to determine the vehicle demand on the airport ingress-egress facilities. There are a variety of possible transportation modes, and the demand split is often difficult to quantify. The possible ingress-egress transportation modes include private automobile, taxi, rental car, limousine, bus, rapid transit, helicopter, and truck. With the exception of the helicopter, these modes belong strictly to the landside segment of the airport. At most airports in the United States, most people enter an airport by private automobile or taxi.

AIRPORT LANDSIDE FUNCTIONAL FLOW REPRESENTATION

Figure 2 shows the airport landside functional flow of the overall traffic movements and activity within the airport. Each facility may represent a network of subfacilities that when linked together support the complex activities of movement and service operations. The traffic movement through the airport landside consists principally of vehicles containing employees, passengers, visitors, and baggage.

Enplaning passenger vehicles entering the airport proceed to a parking lot for long- or short-duration parking, to a rental car check-in area, or to the curbside for unloading. The passengers and visitors then proceed into the terminal. The passenger may wait in the terminal area or proceed to the ticket counter, baggage check-in, car rental check-in counter, or to the airplane gate, where they must pass through a security check before enplaning. Except for enplaning, the order in which these activities can be performed is not necessarily fixed but depends on factors such as the nature and origin of the trip and the terminal geometry.

Deplaning passengers either proceed to another flight or move through the terminal to the airport boundary. Some passengers may need to get their baggage at the baggage claim facilities. Passengers arriving on an international flight must proceed through a customs inspection and an immigration check. Passengers leaving the airport by landside vehicles may require transactions at car rental or intra-airport transit counters or a wait at a curbside or station for a vehicle.

Connecting passengers join in the flow of enplaning passengers in the terminal. The requirements of some transferring passengers are the same as those originating at the airport, and the services are performed at the same facilities. Passengers making interline transfers are generally required to be processed through the security checkpoint. In general, the baggage is transferred from plane to plane by the airline companies.

Employees are generally assigned parking areas or proceed in public vehicles. The flow of employees is to staffing area or duty stations. At the end of the shift they generally proceed outward beyond the airport boundary.

Visitors are generally well-wishers or greeters. Well-wishers proceed with their respective departing passengers to some point within the airport landside, after which they generally depart the airport. Greeters enter the airport and proceed to the parking areas or to the curbside. The arriving passenger is met at some point within the landside, and the group departs the airport.

AIRPORT LANDSIDE LEVEL OF SERVICE

To approach the airport landside problem requires that a measure of congestion be developed that may be correlated with landside factors and used to study the effects of landside operations on level of service.

Levels of service are criteria that indicate how well the airport system is serving the air passenger. Basic criteria that have been identified are passenger travel time, reliability, comfort, orientation clarity, and safety (2). The latter two are largely

Figure 1. Federal capital funding of the airport landside.

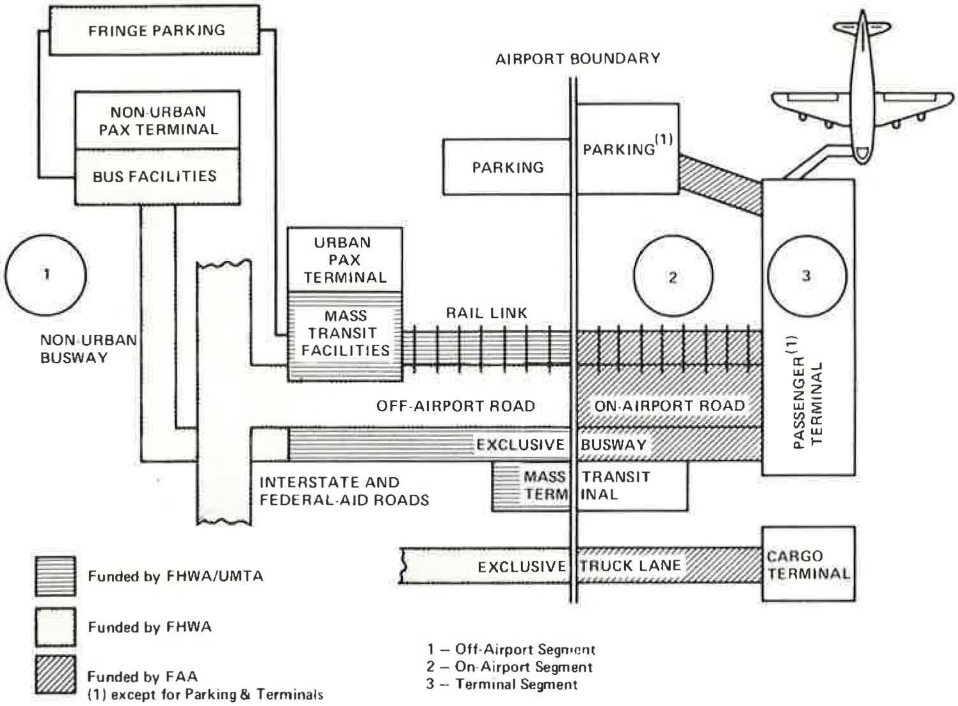
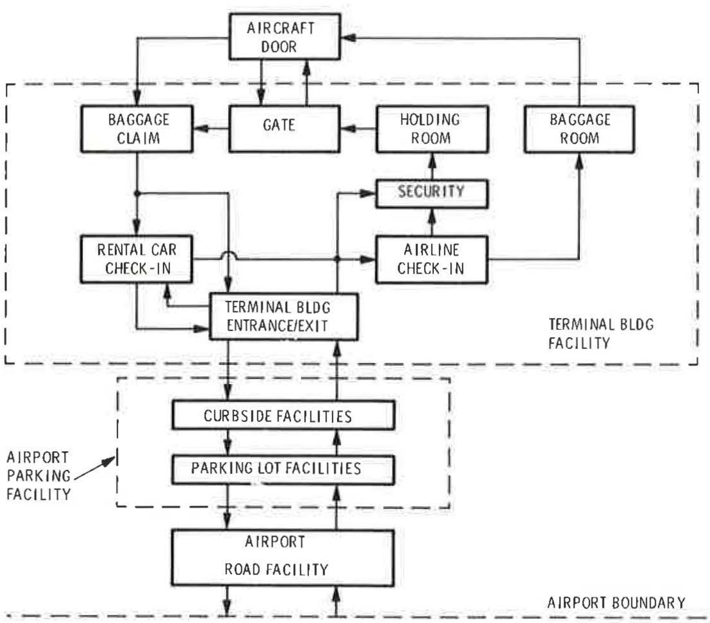


Figure 2. Airport landside functional flow.



qualitative. The first three are interrelated and expressible in terms of congestion parameters. Travel time is dependent on airport layout and may be expressed as a fixed nondelay quantity plus an additional value due to delay. Reliability is the statistical measure of the occurrence of delay. Comfort may be expressed as total walking distance, walking distance while carrying baggage, walking distance while subject to weather elements, total time spent at service counters, and density in terms of passengers per unit area in various holding facilities. The last 2 items are directly related to congestion. Thus, the most widely observed criterion is congestion, as measured in terms of delays, queue lengths, and occupancies. To determine how successfully the airport directs traffic through its roadway system and transfers the passenger from ground modes of transportation to the air mode requires that these parameters be quantified and gathered into a form in which they may be analyzed. This quantification of both congestion and level of service is most effectively described by the passenger delay distribution. Mean values alone are inadequate to describe the process because a significant percentage of passengers can be subjected to large delays without any noticeable effect on the mean.

CHOICE OF METHOD

Three types of methods present themselves for the analysis of landside congestion: experimentation, analytical modeling, and simulation.

An experimental program that would measure airport flow capacity and congestion during peak loading condition is probably unmanageable. The logistics of having large numbers of people participating in experiments is overwhelming. Also, the experiment could needlessly interfere with airport landside operations. In addition, the application of capacities and delay statistics derived from one airport to another is questionable because of the variation in facilities and passenger requirements.

Analytical models, represented by closed-form solutions, are useful in describing flows and delays at a particular facility such as the curbside, ticket counter, or parking lot toll gates. However, the great number of interacting elements in an airport landside complex would require too many simplifying assumptions to permit an accurate description of the complexities of the airport landside. Analytic approaches are further complicated by the independently fluctuating nature of service and arrival rates; that is, steady-state conditions are assumed that may not be achieved at a busy airport with high peaking characteristics.

The simulation method was chosen because it is potentially able to describe the detailed activities of the airport landside in a meaningful and manageable fashion. The simulation model can incorporate a large number of interactions, and rates may be varied in accordance with observed conditions. Simulation models will require some adaptation when applied to different airports, but such adaptation is generally feasible because the basic processes to be simulated are identical from airport to airport. Thus, the range of applicability of simulation methods is broad.

SIMULATION

Two types of simulation models are used for airport landside analysis. They can be classified as accounting models or time-oriented simulation models (3).

Accounting models are macroscopic and deterministic in nature. They operate under invariable rules and do not introduce randomness in the calculations. An example of this is a population counter model, which moves groups of passengers from one airport facility to another according to a predetermined time schedule. The departing passengers arrive at the airport in groups according to a distribution relative to flight times. As time progresses, the groups are advanced through the terminal according to a fixed schedule. No queues occur for this type of accounting model, and service times at any facility are fixed. The output of this model would be the occupancy of given areas as influenced by the flight schedule.

Other accounting models may give averages of delays based on fixed service times. If the demand exceeds the capacity at a given facility, the passengers may be held in storage until the server is available. Service times are fixed for all passengers, and the flow rates past a given point depend on the programmed rules governing flow and the numbers of passengers input to the model during the simulation run. If delay is a function of flow, the relation must be specified in the model.

Time-oriented simulation uses a microscopic approach. That is, it follows the movement of each entity such as an individual passenger or vehicle. This type of simulation attempts to reproduce existing situations at a detailed level, either by the continuous solution of dynamic equations expressing a relation between units or by generating random operating times that have the same distribution as the process being simulated. An example of the first type of simulation would involve relations such as the car-follower law, which is a differential equation relating the acceleration of a given car to the separation distance between itself and the preceding car and the current speeds of the pair. The simulation consists of solving this equation as a function of time for all vehicles in the network. Programmed reactions to the physical environment such as traffic signals are included in this type of simulation.

The second type of time-oriented model uses queuing models wherein probability distributions are used to describe arrival patterns and service processes. Inputs and outputs of this type of model are shown in Figure 3, and a description of the computation for a single server is shown in Figure 4. The input arrival distribution is described in terms of the interval between successive arrivals. These vary stochastically, requiring a probability density distribution, which forms the basis of a random number generator for computing the times of arrival at the service facility. This distribution may change as a function of time. The distributions of service times are also computed by random number generation based on input functions or distributions. The queuing discipline is a description of the relation between the queuing pattern and the service pattern. For many of the facilities of an airport terminal, the discipline is "first-come first-served." If several queues exist, the queuing discipline determines which is selected. The reneging frequency indicates the tendency for a passenger to abandon a line because of excessive length and seek another line or perform another function.

SIMULATION REQUIREMENTS

The general requirements of a computer simulation model to analyze the airport landside are summarized as follows:

1. Operates by using a high-order computer program language;
2. Provides simulation of all significant landside facilities that impact on passenger flows associated with both enplanements and deplanements;
3. Provides flow information, travel time, delay time, occupancy, and queue length as output data in the form of statistical distributions; and
4. Is applicable to large airports (those that process more than 10 million passengers per year).

This model would be used to indicate whether the airport landside and airside achieve a balance, i.e., whether the seats flown in on the airside are accessible from the landside without excessive congestion and whether passengers arriving by air could similarly transfer through the landside expeditiously. The general features of this model are shown in Figure 5.

REVIEW OF EXISTING SIMULATION MODELS

The time-oriented simulation model was envisioned as having the capability of describing the detailed activities of the airport landside. For the purpose of obtaining

Figure 3. Typical inputs and outputs of a time-oriented queuing model.

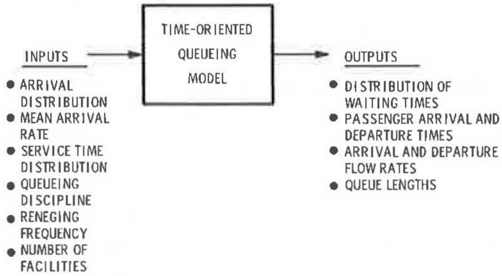


Figure 4. Computation of waiting time in a single-channel service facility.

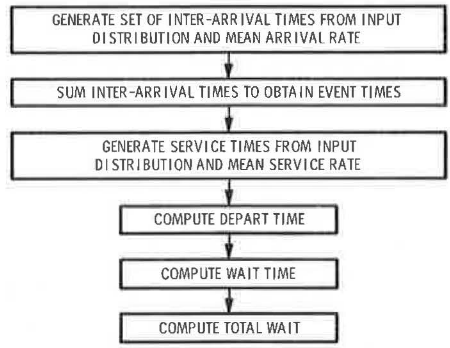


Figure 5. General features of an airport simulation model.

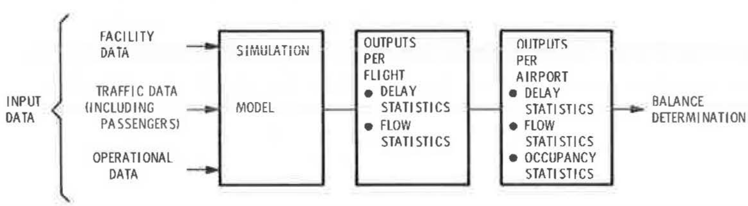


Table 1. Salient features of models.

Model	Language	Boundaries	Type	Input Data	Output Data	Validation	Applicability
Bechtel	GPSS-5	Airport boundary to gate	Time-oriented queuing model	Facility layout and dimensions Flight schedule data Facility service times Passengers	Quantity of passengers/ vehicles/baggage processed Passenger flow times Facility processing and and waiting times	Partial	Applicable, but requires adaptation to provide delay statistics
TAMS	GPSS	Airport boundary to gate	Time-oriented queuing model	Flight schedules Passengers Facility service times Arrival and departure distributions	Quantity of passengers/ vehicles/baggage processed Passenger flow times Queue lengths Facility use	None	Applicable, but requires adaptation to provide delay statistics
PONYA	GPSS-2	International terminal building (gate to curb arrivals only)	Time-oriented queuing model	Terminal building configuration Arrival rates Service time distributions Passengers	Quantity of passengers/ baggage processed Waiting times Queue lengths	Partial	Not now applicable (for arrivals only)
MIT	GPSS	Parking garage to gate	Time-oriented queuing model	Flight schedules Arrival rate function Transit speeds Service time distributions Passengers	Quantities of passengers processed Queue lengths and occupancy distributions Waiting time distributions	None	Not now applicable (configured for metroport concept)
Battelle	Fortran	Airport boundary to gate	Accounting	Flight schedules Arrival percentages Transit times Service times	Population distributions Landside space requirements	None	Not applicable (provides only occupancy data)
Calgary	GPSS	Curbside to gate	Time-oriented queuing model	Number of facilities Storage area capacities Flight schedules Passengers Service time distributions	Quantities of passengers processed Average time/transaction Wait area occupancy Queue contents	None	Not now applicable (extends only from curb to gate)

insight into current techniques, a review of some existing models was performed based on literature supplied by their authors. The purpose for which most of these models were developed was airport design. Examined were simulation models of Bechtel, Inc., Tippetts-Abbett-McCarthy-Stratton (TAMS), Port Authority of New York and New Jersey (PONYA), Massachusetts Institute of Technology (MIT), Battelle Columbus Laboratories, and Canada Ministry of Transport (Calgary). A summary of the salient features of the models is given in Table 1. All models except the Battelle model are programmed GPSS. The major distinctions among the GPSS models are due to the physical extent of the landside modeled and to their applicability to a major hub airport.

The input and output data are only those of a general nature; for example, the passenger data category may be specified further to include the number of persons accompanying passenger, baggage requirements, choice of mode for access or egress, trip purpose, and origin-destination information. Similarly, the outputs furnished by these models may be specified for each facility, that is, for each ticket counter, gate counter, baggage claim device, or any other facility where queuing is simulated.

The level of validation indicates whether some passenger flow information was gathered at an existing airport and compared with the simulation results. A partial validation indicates that this was performed; however, no statistical hypothesis tests were furnished to indicate the level of agreement between measured and simulated results.

The applicability indicates whether the type of simulation performed is adequate to produce the type of distributions desired, namely, that of delays, queue lengths, and occupancies for the total landside. Because most of these are GPSS models, the adaptation from airport to airport may involve some reprogramming; however, the basic desired approach has been demonstrated by the models that are considered applicable. The delay statistics for these simulations were not furnished on an enplanement basis as was the total time of passage through the terminal area produced by Bechtel in Figure 6 and by TAMS in Figure 7 (10). Delays that are calculated and presented in this form are the desired objective of a landside simulation model. In addition, queue lengths at service facilities and occupancies of waiting areas in a distributed form should be available as level-of-service measures.

The Bechtel model is a time-oriented queuing model that can dynamically describe and statistically summarize the passenger flows, transit time distributions, occupancies, and queue lengths. It does not now output passenger delay distribution but can readily be extended to include it. Previous validation efforts have not been sufficient to provide information concerning confidence in the model. The model has been described as consisting of a surface transportation group and a terminal group for the analysis of the airport landside. The terminal model simulates the many passenger and baggage functions within the terminal and the surface traffic on the airport roads. This model now has the capability of simulating 50 gates, 25 rental car counters, 50 airline ticket counters, 50 airline waiting rooms, 16 baggage claim fixtures, and 12 baggage claim areas.

The TAMS terminal and roadway models are time-oriented queuing models that output queue lengths, occupancy, transit time, and use statistics. Delay time statistics are available. No validation effort has been conducted (4). This model now simulates activity in one international module and one domestic terminal at one time. The size of each of these is unspecified, and the numbers of facilities simulated are not furnished.

The PONYA terminal model applies only to arrivals at an international terminal facility. Some validation effort was conducted, but little information was published. No roadway or curbside modeling is present in this model (5). Both passenger and baggage movements from the aircraft to the building lobby are simulated. Federal inspections and baggage claim operations are the major facilities that are analyzed through use of this model.

The MIT metroport simulation model is time oriented and based on queuing models. It is designed to study a metroport at which vertical takeoff and landing aircraft operate. Interarrival times of enplaning passengers are based on Poisson distributions; the arrival rate is based on the distribution of passengers arriving at the terminal prior

Figure 6. Passage time through terminal area by Bechtel model.

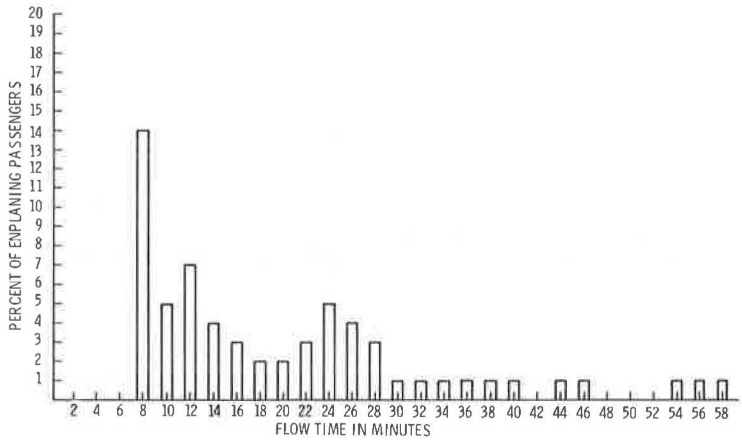


Figure 7. Distribution of deplaning passenger transit times (gate to curb) by TAMS model.

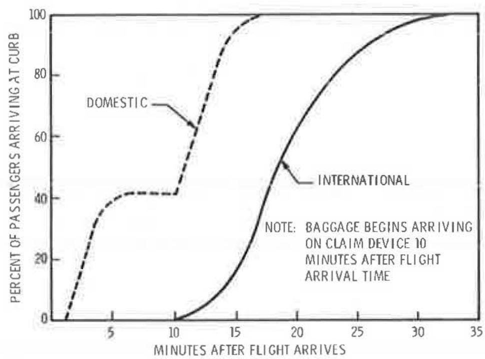


Table 2. Landside factors and distribution used in models.

Factor	Bechtel	TAMS	PONYA	MIT	Battelle	Calgary
Ticket counter times	Distribution	Distribution	Distribution	Distribution	Fixed	Distribution
Walking speeds	Fixed	Distribution	Distribution	Distribution	Fixed	Fixed
Vehicle speeds	Fixed	Fixed	NA[a]	NA	NA	NA
Group size	NI[b]	Distribution	Distribution	Distribution	Distribution	NI
Passenger-visitor ratio	Fixed	Distribution	NI	Distribution	Diurnally varying ratio[c]	Distribution
Bags/passenger	Distribution	Fixed	Distribution	Distribution	NA	Distribution
Modal choice	Distribution	Distribution	NA	Distribution	NA	NI
Passengers/automobile	Fixed	Distribution	NA	NI	Fixed	Fixed
Curb occupancy dwell times	Fixed	Distribution	NA	Distribution	Fixed	Distribution

[a]Not applicable to the simulation considered. [b]No information available. [c]Used as a fixed number during the time interval being calculated.

Table 3. Simulation performed according to facility and traffic movements.

Item	Bechtel	TAMS	PONYA	MIT	Battelle	Calgary
Facility						
Roadway	Yes	Yes	No	No	Yes	No
Entrance parking lot	Yes	Yes	No	No	No	No
Parking lot search	No	No	No	No	No	No
Curbside queuing dwell	Yes	Yes	No	Yes	Yes	Yes
Ticketing check-in	Yes	Yes	No	Yes	Yes	Yes
Walkways	Yes	Yes	Yes	Yes	Yes	Yes
Security	Yes	Yes	No	No	Yes	Yes
Gate counter	Yes	No	No	Yes	No	No
Baggage claim	Yes	Yes	Yes	Yes	Yes	Yes
Verticle movement devices	No	Yes	No	Yes	No	Yes
Customs	No	Yes	Yes	No	No	Yes
Traffic movements						
Automobile	Yes	Yes	No	No	Yes	No
Bus	Yes	Yes	No	No	No	No
Taxi	Yes	Yes	No	No	No	No
Passenger	Yes	Yes	Yes	Yes	Yes	Yes
Visitor	Yes	Yes	No	Yes	Yes	Yes
Baggage	Yes	No	Yes	No	No	No
Employees	Yes	Yes	No	No	No	No
Limousine	Yes	Yes	No	No	No	No
Rental car	Yes	Yes	No	No	No	No

to flight time. Service times are based on data-derived distributions as are those of the previous models. The model does not simulate activities on roadways but does include the curbside and a transit station platform. This model is now configured for a 3-level terminal with 4 pads to accommodate the VTOL aircraft. The basic approach for simulation of the landside exists in this model, but an expansion to accommodate the total landside would be required (6).

The Battelle landside model is a deterministic population counter programmed in FORTRAN and designed to compute occupancies of various terminal areas such as baggage and ticketing areas and gate lounges. Enplaning passengers are formed in groups, which arrive at the airport according to a distribution relative to flight times. All groups are processed through landside functions at a fixed rate, independent of the numbers of passengers present at any given facility. Although mean delay times for groups are not explicitly calculated, the program may be extended to include this capability. The advantage of this simulation is that it may be applied to a large number of airport geometric configurations. Presumably, this model could perform as a time-oriented simulation and produce delay distributions by calculating delays for extremely small time intervals such that the passenger group sizes would shrink to a 1-passenger limit. The usefulness of this model would then become a question of computer efficiency as compared to the GPSS models (7).

The Canada Ministry of Transport model is another time-oriented simulation that models flow times from the curbside to the enplaning-deplaning gate. Because of the limited requirements of the terminal, the model only simulates some 4 or 5 ticket and baggage counters (8).

A summary of the factors used in describing the landside and a classification as to whether a distribution or fixed value was used are given in Table 2. Those that directly influence the passenger's time spent in the airport landside are the ticket counter service times, walking speeds, vehicle speeds, curb occupancy times, and the baggage/passenger ratio. The modal choice distribution will affect the flow of landside vehicular traffic and thus may contribute to the delays encountered. The passenger/automobile ratio affects unloading times at the curb and thus also contributes to the time spent in the landside. The occupancy of the terminal areas will be a function of the passenger group sizes and the visitor-passenger ratio. No model uses distributions for all functions. The degree of success of including or ignoring the use of a distribution for some function requires validation based on experimental observations.

Table 3 gives the simulations performed by each model according to airport facility and essentially indicates the completeness of each model, at least in terms of representing the operations of the various airport facilities. The Bechtel and TAMS models provide the most complete simulations of the airport landside facilities. With the exception of vertical movement devices and possibly custom facilities, the Bechtel model represents all facilities. The TAMS model is also virtually complete with the exception of parking lot and gate counter facilities models.

Table 3 also gives an indication of the completeness of the various models in representing the various traffic classes within the airport landside. The Bechtel and TAMS models provide the most complete simulation of the various airport landside traffic classes. The Bechtel model represents all traffic classes, and the TAMS model represents all traffic classes with the exception of baggage traffic.

CONCLUSIONS

A review of these existing simulation models indicates that the Bechtel and TAMS models most closely meet the stated requirements. They can produce the required distributions of delay, queue lengths, and occupancies for the boundaries specified. The major adaptation that would appear necessary to complete the landside analysis capability would be including a model of the curbside as a server of finite capacity rather than representing the time spent at curbside as a dwell time.

Run time and cost information suitable for comparisons of program efficiency were not available. In addition, validation of airport landside simulation models requires

considerable additional effort. An extensive data collection effort should be undertaken to provide a data base for further model comparisons and validation.

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