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THE APPLICATION OF SIMULATION METHODS TO INTRA-AIRPORT LANDSIDE PROBLEMS

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16. Abstract

This report describes methods of analyzing the flow of people through the airport landside, which is defined as extending between the airport boundary and the arrival/departure gates. Passenger delay for specified flow and holding values is taken as the desirable measure or level of service. Simulation is determined as the best method of analysis.

Two types of simulation techniques are described. The deterministic accounting model evaluates mean delay or occupancies. The time oriented queueing theory model determines delay or occupancy distributions. Time oriented simulation is demonstrated as most accurately representing the stochastic interrelationships among the various landside elements.

Various existing models are reviewed and two are recommended as offering potential applicability to investigate airport landside traffic. It is recommended that at least one of the chosen simulations be validated.

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PREFACE

This report was sponsored by FAA AEM-200 to promote efficient airport landside operations. Methods of analyzing the flow of people through the airport landside are described; simulation is observed as being the best method of analysis. The report documents a review of various simulation models and indicates the applicability of each in investigating airport landside traffic.

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1. INTRODUCTION

Air transportation has dramatically reduced long distance travel time. Airline passengers can now travel from the east coast of the United States to California in five hours air time. Further reduction in total travel time is constrained, however, by airport delays which in certain instances are comparable to air travel time. Thus, additional and significant savings in overall travel time with attendant dollar savings and other benefits, can only be achieved by reduction of airport delays.

Airport delays are, for the most part, due to airport landside congestion; landside being defined as that part of the airport from the airport entrances/exits to the arrival/departure gates. Landside airport congestion represents the ultimate limitation to airport growth according to the FAA. Parameters that influence airport landside capacity have been studied to some extent and various techniques have been explored to increase the effective operational capacity of airports and thereby reduce congestion and associated passenger delays.

Computer simulation offers an effective and realistic approach to further studying the airport landside problem as a system. In view of the complexity and dynamic nature of the problem, computer simulation may be the only feasible and viable approach. This report describes how simulation of airport landside activities can be used to accurately determine the landside flow and holding capacities and the associated delays. Attainment of this goal will require validating the computer model against the airport landside system it simulates. This must be done by performing statistical comparisons between measured and computed quantities which, in turn, will require an extensive data base.

This report reviews several airport landside computer simulation models that have been developed recently, classifying and evaluating them in terms of applicability and level of validation. The models discussed include ones developed by Bechtel Corporation, Tippetts-Abbett-McCarthy-Stratton (TAMS), the Port of New York Authority (PONYA), Massachusetts Institute of Technology, Battelle Columbus Laboratories, University of Waterloo, and the Canadian Ministry of Transport. The study recommends two models, the Bechtel and TAMS, for further study and evaluation. These models appear to be most potentially extendable to dynamically measuring the impact of congestion on airport level of service, using passenger delays as the principal level-of-service measure.

2. PROBLEM DEFINITION

2.1 OVERALL DESCRIPTION

The primary purpose of an airport complex is to transfer passengers from the ground transportation system to the air transportation system (and vice versa), or to transfer passengers between portions of the air transportation system itself. A simplified example is shown in Figure 2-1. Airport planning and design has been the subject of much study because of the importance of airports in the overall air traffic system[(1)*]. An airport consists of three subsystems: the airspace (including runways), the airside (including runway turnoffs and airline gates), and the landside (including everything from the gates to the airport boundaries). This report is concerned with the landside element.

The controlling parameter for all landside operations is aircraft movement and consequently the airline flight schedule orders almost all activities within the airport boundaries. Based

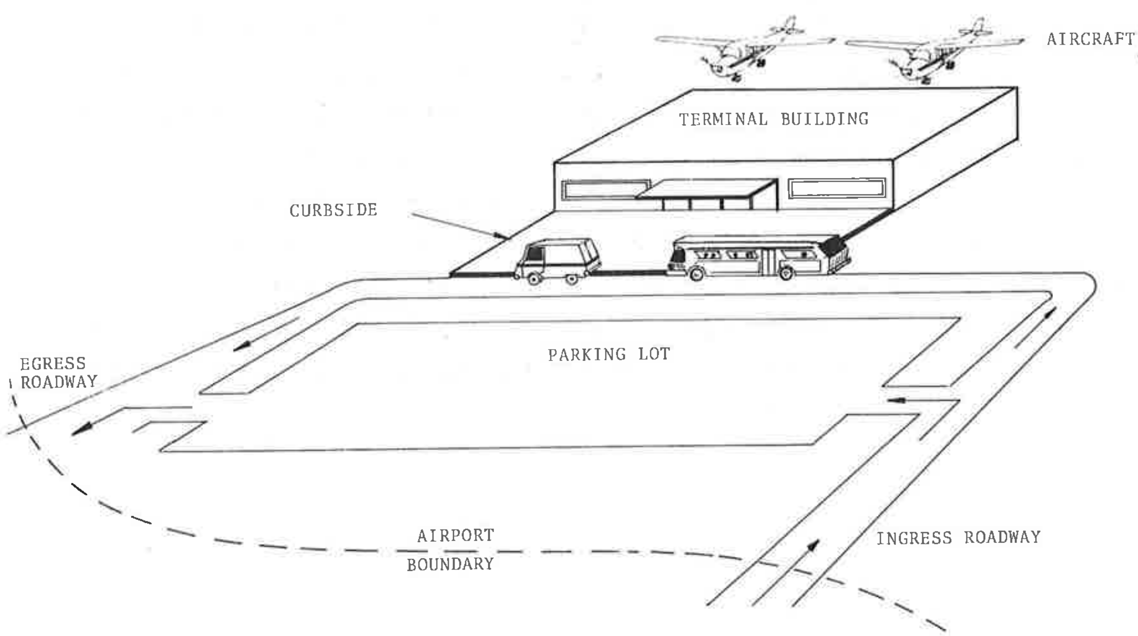

Figure 2-1 Typical Airport System Complex

on aircraft class, flight schedule and loading factors, the passenger demand on landside facilities can be calculated.

Landside traffic can be divided into three categories.

People
Baggage
Cargo (including mail)

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 sub-facility is portion of a facility concerned with some sub-activity.

Landside facilities fall into three types: (1) access/egress, (2) processing and (3) concessionary. Table 2-1 illustrates typical facilities of each of these three types.

Typically, the airport population divides itself into three major groups: air passengers, employees of the airport complex, and airport visitors. Air passengers represent the independent variable which governs all airport activities directly or indirectly. Air passenger demand significantly fluctuates as a function of hour of the day, day of the week, and month of the year. It is also dependent on air transportation cost and convenience. Air passengers are frequently not the largest element of the total airport population. Visitors and employees often outnumber passengers and can place a greater demand on certain landside system facilities than air travelers. For example, the employee demands on the airport landside complex can be significant, showing up as vehicle loads imposed on the ingress/egress system, which tend to correlate with passenger and visitor loads.

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*All references are given in Appendix A.

TABLE 2-1 AIRPORT LANDSIDE FACILITIES

Access/Egress Facilities
1) Airport road system
2) Rapid transit system
3) Parking lot/parking spaces
4) Sidewalks
5) Corridors/guideway
6) Baggage and cargo moving equipment
7) Terminal building
8) Passenger facility (lobby and waiting rooms)
9) Cargo storage facility
Processing Equipment Facilities
1) Ticket counters
2) Security
3) Boarding area
4) Baggage check-in
Concession/Amenity Facilities
1) Gift shops
2) Lunch shops
3) Restaurants
4) Barber shops
5) Lavatories

Visitors fall into two general categories: (1) passenger related visitors and (2) all other visitors (sightseers, service people, etc). Typically, the number of passenger-related visitors varies from 40 to 80% of the number of air passengers with the lower percentages occurring at domestic airports and the higher percentages occurring at international airports. The number of other visitors is also significant and is quite susceptible to many factors. It can vary from 10% to 80% of total air passengers and typically has a value of 30% at larger airports.

The vehicle demands upon the airport ingress/egress facilities are difficult to determine. There are a variety of possible transportation modes, as shown in Table 2-2, and the demand split is difficult to quantify. With the exception of the helicopter, these modes belong strictly to the landside segment of the airport. At the majority of airports in the United States, most people entering or leaving an airport do so by private automobile or taxi.

TABLE 2-2 LANDSIDE INGRESS/EGRESS TRANSPORTATION MODES

1) Private Automobile
2) Taxi
3) Rental Car
4) Limousine
5) Bus
6) Rapid Transit
7) Helicopter
8) Truck

2.2 AIRPORT LANDSIDE FUNCTIONAL FLOW REPRESENTATION

Figure 2-2 is a functional flow block diagram of the airport landside activities. Each facility may represent a network of subfacilities which, when linked together, support the complex activities of movement and service operations. The traffic movement through the airport landside consists principally of pedestrians, and 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 passengers may wait in the terminal area or proceed to the ticket counter, baggage check-in, or the 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

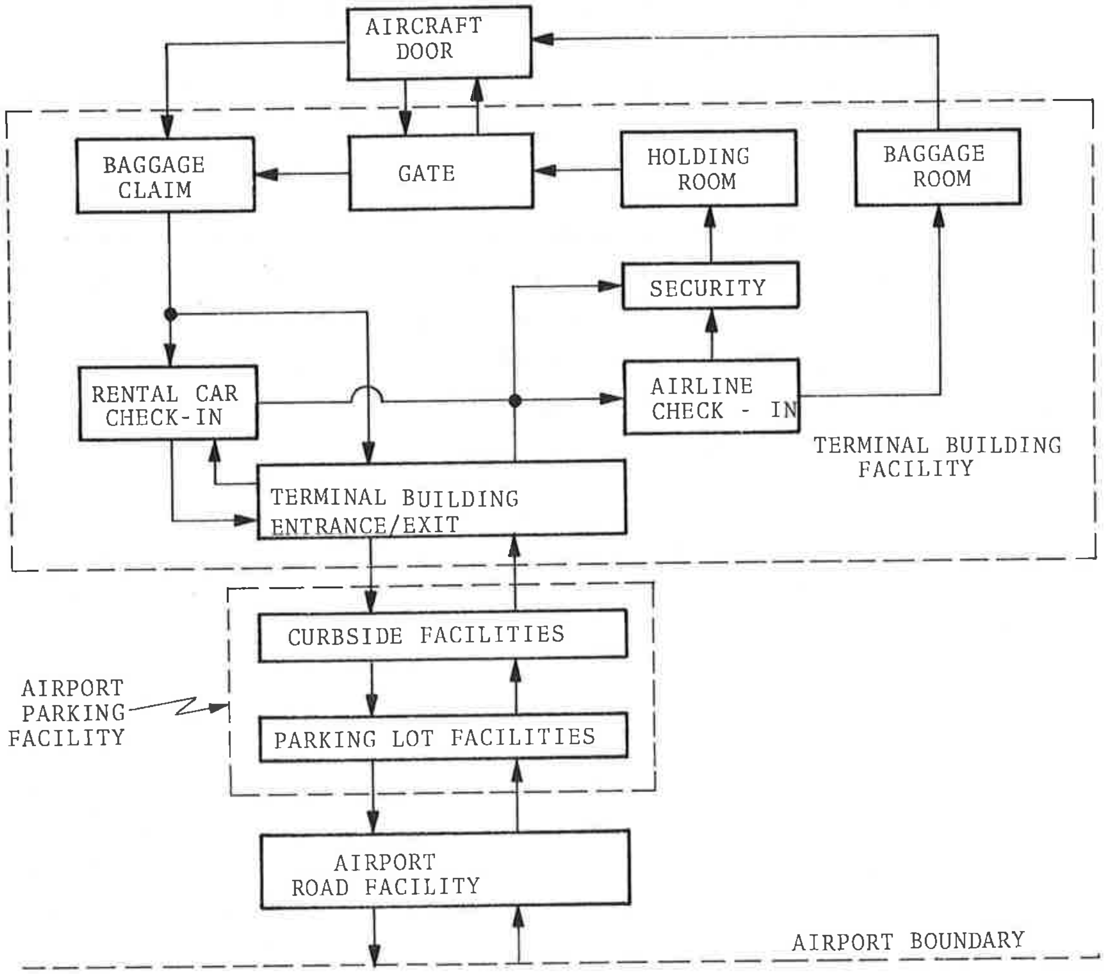


Figure 2-2 Airport Landside Functional Flow Block Diagram

can be performed is not necessarily fixed and depends upon 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 at their destination on an international flight must proceed through a customs inspection and an immigration check. Connecting passengers on international flights must perform these functions before proceeding to connecting flights. Passengers leaving the airport by landside vehicles may be delayed by transactions at car rental or intra-airport transit counters or by a wait at a curbside or station for a vehicle. The passengers then generally proceed outward past the airport boundary.

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

Employees driving their own cars are normally assigned parking areas. Alternatively, they may use public vehicles. The flow of employees is generally toward staffing areas or duty stations. At the end of the shift employees generally proceed outward beyond the airport boundary.

Most visitors are 'well wishers' or 'greeters'. Well wishers proceed with their respective departing passengers to some point within the airport landside, after which they usually 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.

2.3 STATEMENT OF PROBLEM

Reductions in overall travel time, significant dollar savings and such benefits as improved passenger relations can be achieved by reducing airport landside congestion. Measures of airport landside level-of-service need to be developed and correlated with landside factors as a basis to determine ways of reducing congestion at existing airports and for use as a design tool in developing new airports.

2.3.1 Airport Congestion

Congestion results from inadequately meeting traffic demands. Congestion can arise in two ways: (1) the traffic demands approach or exceed the capacity of the facility and 2) a service facility malfunctions or some reduction in service reduces the effective capacity of the service facility. Congestion normally shows up as queues. Queue length may increase very rapidly as the traffic demands exceed the facility capacity. The facility capacity is defined as the maximum flow of traffic through the facility measured in passengers per hour. Congestion is usually associated with peak hour arrival rates. As the arrival rates increase, congestion is manifested by longer queues at service facilities and an increase in associated delay times.

2.3.2 Airport Landside-Level-of-Service

The output of airport landside analyses should be measures of the airport landside level-of-service[2] based on specific input data as shown in Figure 2-3. There are many possible measures of airport service such as yearly passenger flow, operations per hour and peak hour demands. However, the work reported here has assumed that passenger delay for specified flow and holding times is the desired measure of level-of-service for future studies. Passenger delays, queue lengths, holding capacities and passenger flow were therefore the pertinent variables considered in this study. One of the important objectives was to confirm the assumption that computer simulation was the most feasible and potentially fruitful method of investigating landside traffic and to lay the groundwork for developing a simulation model for such future studies.

Figure 2-3. The Output of the Airport Landside Analysis

2.3.3 Delay Distributions

The impact of landside congestion on an airline passenger can be measured by delay which, in turn can be expressed by delay distributions as described by Gordon[3]. The passenger delay can thus be expressed in terms of the following functions:

Probability distribution of passenger delay is less than time t

Probability distribution that the time to complete facility service is less than time t

Probability distribution that the time spent waiting for service is less than time t

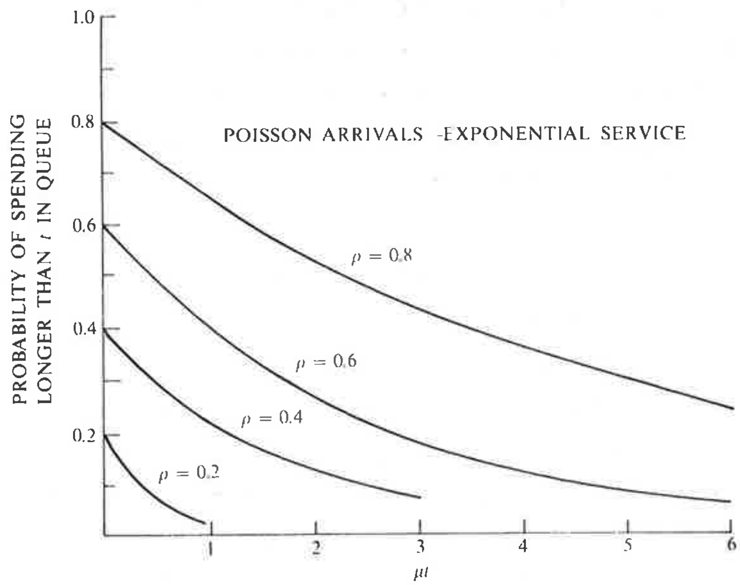
An example of a probability distribution of delay resulting from congestion is shown in Figure 2-4. In this case, the probabilities represented are complements of those previously specified as delay distributions. The curves represent the probability that the time required to complete the transaction is greater than time t.

The distribution function is maximum at $t = 0$ and cannot increase with t. Therefore, one of the objectives of an airport design is to keep the probability P(o) at $t = o$ as small as possible. However, a low value of P(o) does not necessarily guarantee a satisfactory system since, for that, the probability at large values of t may not become insignificant. Figure 2-4 presents the delay probability as a function of μt, parametric in ρ, where

μ = Mean service rate

ρ = Ratio of arrival rate to service rate.

As can be seen, increasing the mean arrival rate and/or decreasing the mean service rate tends to increase the probability that the passenger will spend a time greater than time t in the facility.



Reference 3

Figure 2-4 Probability of Passenger Delay

2.4 CHOICE OF METHOD

The determination of airport landside capacities and delays may be performed by three methods: experimentation, analytical modeling, and simulation. Although a detailed cost-benefit analysis was not performed, the important criterion used for selection of the method to be recommended and further considered was the ability to describe the detailed activities of the airport.

An experimental program which would involve a test of the airport flow capacity by enacting peak loading processes was considered unmanageable. The logistics of having several thousands of participants for off-hour experiments appeared overwhelming but performing the experiment during busy hours might needlessly interfere with airport landside operations. In addition, the applicability of capacities and delay statistics for a given airport to other airports is questionable.

Analytical models which are represented by closed form solutions of equations are useful in describing flows and delays on a gross level at a particular facility such as a curbside, ticket counter or toll booth. However, the great number of interacting elements in an airport landside complex would require too many simplifying assumptions to permit describing the detailed activities by analytic methods. Analytic approaches are further complicated by the independently fluctuating nature of service and arrival rates.

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

The simulation model opens up the possibility of easily and quickly determining the impact of changed input variables and the sensitivity of the airport landside operation to such changes. For example, flight operations can be simulated and changes made to determine the resulting matching requirements on facility operating schedules, employee work shift schedules, passenger/visitor routing, costs, and other airport landside elements.

2.5 THE SIMULATION OF THE AIRPORT LANDSIDE SYSTEM

The intent of landside simulation is to determine flows and delay statistics on a per-flight basis, and flow, holding capacities and delay statistics on an airport-wide basis. Simulations have already been applied by airport planners to test and evaluate proposed airport designs to a certain degree. Such features as inadequate or poorly placed ticket counters, or overly long corridors between transfer gates have been caught and eliminated early in the design by such methods. In addition, maximum passenger flows and the holding capacities of various elements can be studied for indications of an airport's future ability to provide services.

The general features of an airport landside simulation are shown in Figure 2-5. The prime simulation objective is to determine the compatibility between airside and landside activities. This compatibility is indicated by the matching, at the gate, of passengers with seat flow such that landside delays encountered by some specified percentage of passengers is less than a chosen value t. (See Section 2.3.3.) Acceptable values of delay, t, need to be determined by such interested parties as airlines, passengers, government and others.

Simulation inputs are derived from observations of the specific airport to be simulated. However, some aspects such as operational data, may remain constant from one airport to another and are applicable to any airport. The traffic data input refers to passengers, visitors, employees, baggage and vehicles. The outputs on a per-flight basis are a count of those who arrive at the aircraft for seating. The output also includes a distribution of delays. The total flow through the airport and a summation of the delay and occupancy statistics can be used to determine the airport capacity.

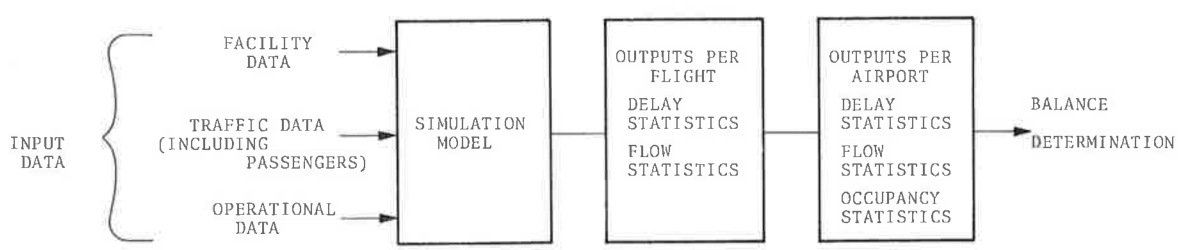


Figure 2-5 General Features of an Airport Simulation Model

3. SIMULATION OF AIRPORT LANDSIDE MODELS

Computer simulation of an airport landside system complex requires the formulation of a mathematical model which represents the landside traffic behavior. Using simulation techniques, complex system operation can be dynamically studied and the effects of parameter variations determined to assist in optimizing design and operation to any desired criteria. However, to establish a computer simulation model for a system as complex as an airport landside traffic system a clearly defined methodology is required.

3.1 METHODOLOGY

A simulation computer model requires, in order,

Problem Definition
Model Requirements
Mathematical Models
Computer Program Requirements
Computer Programs
Field Data
Simulation Experiments
Computer Model Validation

Figure 3-1 presents these steps as a block diagram, providing a methodology for developing the airport landside simulation model. This block diagram outlines the sequence of events and their interrelationships.

An overall understanding of landside traffic is required to define the airport landside problem. Accurate problem definition is crucial to the success of the simulation. Problem definition should explicitly cover the objectives of the work, so that model requirements can be established. The data collection effort is needed to provide both input data and data to be used in the validation effort. The data may also assist in the problem definition. The formulation of the mathematical model and the associated computer program should consider that the airport landside

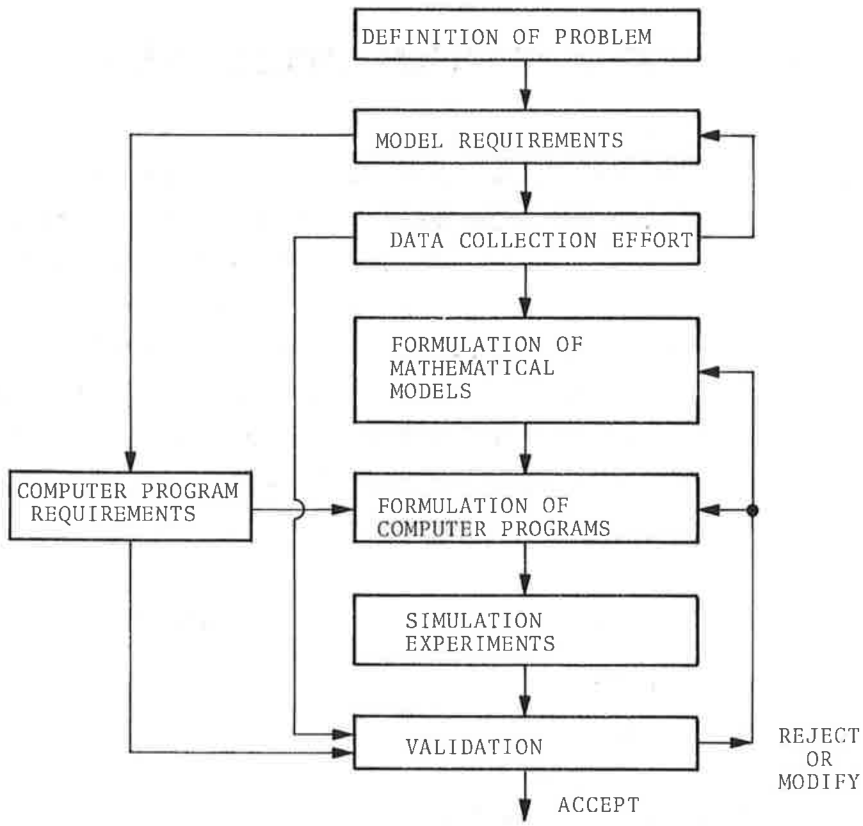


Figure 3-1 Methodology for Developing the Airport Landside Simulation Model

is a dynamic system with complex, time-varying interactions. The simulation model must provide a measure of airport landside level-of-service. The validation effort establishes the model validity by correlating the simulation output data with measured field data and determines, if indeed, the simulation model meets the model requirements.

3.2 MODEL REQUIREMENTS

The airport landside model is a mathematical description of the airport landside system. The landside traffic activities are described by mathematical functions that interrelate the significant landside parameters. The requirements of the model are as follows:

The model should dynamically represent the landside traffic behavior as a function of time.

The model should dynamically represent the traffic interrelationships between facilities within the airport.

The model should accurately represent the traffic parameters using accepted mathematical modeling methods.

The model should be relevant to the study objectives.

The model must possess multi-stage development capability; after meeting short term requirements, additional development should render it capable of meeting long term requirements.

The model should be organized in building blocks, using sub-blocks to simplify handling of interactions and to represent more functionally the traffic flows within the airport.

The model should provide measures of airport landside level of service.

3.3 DATA REQUIREMENTS

3.3.1 Input Data for Simulation Model

The landside simulation model requires certain input data to represent an actual airport landside system. This input data can be classified into three categories:

Facility data
Traffic data
Operational data

The facility data encompasses a layout and dimensional description of the landside complex. Table 3-1 presents the types of facility data required. Note that the facility data may include information as to facility position. This can probably be accomplished by assigning each facility a position on an X, Y, Z grid system. The linkage lengths can be determined using a routing strategy.

TABLE 3-1 AIRPORT LANDSIDE FACILITY INPUT DATA

FACILITIES	POSSIBLE DATA REQUIRED
Roadway	Layout, Length, Width (Number of Lanes), Number, Positions
Parking Spaces	Layout, Length, Width, Number, Positions
Curb Spaces	Length, Number, and Position
Toll Booths	Number and Position
Terminal Buildings	Number and Position
Entrance/Exit	Number and Position
Check-in Counters	Number, Airline Allocation, Position
Concourses	Number, Position, Length, Width, Layout
Security Check	Number, Position
Corridors	Number, Position, Length, Width, Layout
Holdrooms	Number, Position, Area
Gates	Number, Position, Airline Allocation

The traffic input data is a description of the essential airport landside driving function(s) and associated information needed to simulate the total spatial and temporal demand of the landside system. The principal inputs are the aircraft gate arrival and departure times which translate into passenger flows. The traffic data input provides a list of all flights in and out of the airport for the period of interest. Table 3-2 presents the aircraft and flight related information required as input. The passengers-per-flight, translated to passenger demands upon the airport, is of particular interest. Other traffic parameters which are necessary to compute the other demands upon the airport complex (visitors, ground vehicles, employees, baggage, etc.) are also presented.

The input operational data is a quantitative description of how the traffic and airport landside facilities behave or operate. Table 3-3 presents a list of the most important operational input factors that are required to simulate an airport complex. Note that the facility operating schedules form the major part of this data.

TABLE 3-2 LIST OF TRAFFIC INPUT DATA

AIRCRAFT AND FLIGHT RELATED INFORMATION	GROUND VEHICLE RELATED INFORMATION	PEOPLE RELATED INFORMATION	BAGGAGE INFORMATION AND OTHER
Gate Number Flight Number(s) Airline Aircraft Type Aircraft Capacity Passengers Per Aircraft - Arriving - Departing - Connecting - Through Quantity of Baggage - Arriving - Departing - Connecting - Through	Average Passengers Per Vehicle Type Average Employees Per Vehicle Type	Visitors/ Passengers Total Number of Employees at Airport	Baggage Per Passenger

TABLE 3-3 OPERATIONAL INPUT DATA

Airline Flight Schedules
Rapid Transit/Bus Schedules
Employee Work Schedule and Landside Employee Distribution
Facility/Sub-facility Operating Schedules and Service Times
Passenger/Visitor/Vehicle Routing Strategies through Airport Complex
Passenger/Visitor/Vehicle Average Transit Velocity
Passenger/Visitor Personal Habits

3.3.2 Output Data for Landside Simulation Model

The landside simulation model outputs three basic types of information.

Passenger and baggage flow data

Passenger and baggage count (occupancy) and queue length

Passenger and baggage processing time and delay distribution

The flow data is basically a count of the traffic passing a specific point within the airport complex for some time interval. Table 3-4 illustrates the several flow outputs of interest. The periods of peak traffic flow are of particular interest. Table 3-5 illustrates that the flow data will be collected for individual facilities and sub-facilities, as well as for the accumulative flows in and out of the airport complex. This will allow an examination of the effect of individual sub-facility flows on the total flow.

TABLE 3-4 TRAFFIC FLOW REGIONS OF INTEREST

AIRCRAFT FLOW	GROUND VEHICLE FLOW	PASSENGER FLOW	BAGGAGE FLOW
Gate Airline Terminal Airport	Airport Entrance/Exit Parking Lot Entrance/Exit Curbside Entrance/Exit	Parking Lot Entrance/Exit Parking Lot to Terminal (Arrivals and Departures) Terminal Building Entrance/ Exit Airline Ticket Counters Security Areas (Arrivals and Transfers) Gate (Arrival, Departure and Transfers) Rental Car Counter (Departure)	Baggage Equipment Airline Terminal Airport

TABLE 3-5 TRAFFIC FLOW DISTRIBUTIONS

AIRCRAFT FLOW DATA (ARRIVALS AND DEPARTURES	GROUND VEHICLE FLOW DATA (ARRIVALS & DEPARTURES)	PASSENGER FLOW DATA	BAGGAGE FLOW DATA (ARRIVALS & DEPARTURES AND TRANSFERS
Aircraft Per Hour Aircraft Per Day Seats Per Hour Seats Per 10 Minutes	Automobiles Per {10 Minutes, Hour, Day} Buses Per {10 Minutes, Hour, Day} Trucks Per {Hour, Day} Taxis Per {10 Minutes, Hour, Day} Trains Per {Hour, Day} (if applicable)	Passengers per {Minute, 10 Minutes, Hour, Day} (Arriving, Departing, Transferring) Visitors per {Minute, 10 Minute, Hour, Day} Employees per {Hour, Day}	Bags per {Minute, 10 Minutes, Hour, Day}

The count data is basically the instantaneous occupancy of certain facilities generally categorized as holding rooms. This information is important in evaluating the holding capacity of various airport facilities and sub-facilities. The periods of peak occupancy during the day are of particular importance. Table 3-6 presents a list of holding areas whose occupancy must be measured. Passenger occupancy is broken down in terms of arrival, departure and transfer occupancies. Table 3-7 presents the list of occupancy data to be collected. Queue lengths at the various service counters are also included.

Passenger and baggage processing time and delay distributions are those distributions which arise from aggregating all of the processing or delay times on a per-flight, per-gate, or per-enplanement basis. As each passenger or piece of baggage is processed, processing times are calculated and added to the individual's total. At the end points of the simulation, either at the airport gate or airport boundary, the total time is included in the statistical distribution of times of persons on the same flight or using the

TABLE 3-6 HOLDING AREAS TO BE MEASURED FOR OCCUPANCY

AIRCRAFT OCCUPANCY	GROUND VEHICLE OCCUPANCY	PASSENGER OCCUPANCY	BAGGAGE OCCUPANCY
Airline Gate Area	Parking Area(s)	Terminal Building	Baggage Equipment
Terminal Building	Curbside	Waiting Areas	Airline
Airport	Terminal Building	Service Areas	Terminal Building
	Airport	Airport	Airport

TABLE 3-7 OCCUPANCY MEASURES (DISTRIBUTIONS)

AIRCRAFT OCCUPANCY MEASURE	GROUND VEHICLE OCCUPANCY MEASURES	PASSENGER OCCUPANCY MEASURES (ARRIVALS-DEPARTURES-TRANSFERS)	BAGGAGE OCCUPANCY MEASURES (ARRIVALS-DEPARTURES-TRANSFERS
Aircraft/Airline	Automobile/Parking Area	Passengers/Waiting Area	Bags/Baggage Claim Equipment
Aircraft/Terminal	Automobiles/Curbside	Passengers/Terminal	Bags/Airline
Aircraft/Airport	Taxi/Curbside	Passengers/Airport	Bags/Terminal
	Buses/Curbside	Passengers/Service Area	Bags/Airport
	Automobiles/Terminal Building	Queue Length	Queue Lengths
	Queue Lengths		

same gate. Delay time statistics are gathered in the same manner. The delay times are those times spent waiting in queues for a service, or those times greater than the individual would have normally spent in transiting, caused by such things as walking at a restricted pace because of congested conditions.

Validation requires that field data be collected and reformatted for comparison with the simulation output. This is more fully described in Section 3.8. The formats of the two must be compatible. Flow time data must be collected between selected points in the airport complex to measure individual facility effects as well as accumulated delays. The flow time data basically includes the flow component's transit time distribution, the service time distributions, the waiting time distributions, and the passenger delay distributions. Table 3-8 presents the traffic flow time data that must be computed.

3.3.3 Methods of Data Collection

The airport landside simulation model requires extensive data for operation and for establishment of accuracy and validity. The basic data that must be collected includes both the model input data described in section 3.3.1 and the validation data described in section 3.3.2. The data collected must describe the whole airport landside system.

Much of the facility information should be easily obtainable from the airport authority. Also, much of the traffic and operational data is obtainable from either the airport authority or airlines. Table 3-9 presents a list of the information that can be obtained from these sources. In effect these sources already continuously monitor certain traffic flows.

Additional information needed for model validation can be obtained by continuously measuring the actual traffic flows of aircraft, ground vehicles, people, baggage, cargo, and mail over a 24 hour period. Possible monitoring methods include:

TABLE 3-8 TRAFFIC FLOW TIMES (DISTRIBUTIONS)

AIRCRAFT FLOW TIMES (ARRIVAL-DEPARTURE)	GROUND VEHICLE FLOW TIMES (ARRIVAL-DEPARTURE)	PASSENGER FLOW TIMES (ARRIVAL-DEPARTURE-TRANSFER)	BAGGAGE FLOW TIMES (ARRIVAL-DEPARTURE-TRANSFER)
Gate Waiting Time	Airport Boundary to Parking Lot Entrance Time (Auto) Parking Lot Toll Service Time Parking Service Time (Arrival) Airport Boundary to Curbside Time (Auto, Taxi, Bus) Curbside Waiting (Dwell) Time Parking Lot Time Curbside to Airport Boundary Time Parking Lot Service Time (Departure) Parking Lot Toll Service Time Parking Lot to Airport Boundary	Parking Lot to Curbside Curbside to Terminal Door Terminal Door to Ticket Counter Service Time at Ticket Counter Ticket Counter to Security Service Time at Security Security to Waiting Area Boarding Time Waiting Times (Lobby, Restaurants, Lavatory, Boarding Area) Gate to Baggage Claim Baggage Claim Service Time Baggage Claim to Terminal Exit Terminal Door to Curbside Curbside to Parking Lot Passenger Waiting Time (Curbside) Passenger Delay Distributions	Baggage Transit Times Baggage Waiting Times Baggage Service Times

Movies or video-tape
Traffic counters
Passenger surveys
Human observers

Movies or video tape are an excellent method of obtaining permanent temporal and spatial records of the landside response to the total traffic demands. Movie cameras or video tape cameras/recorders can be placed at critical points and time-synchronized. Movies or video tape recordings can also be made from a helicopter platform above the airport to give a 'total' view of ground and air traffic.

Traffic counters are needed to measure the traffic as a function of time at key points in the airport, especially within the terminal building. Key points include the terminal entrance, concourses, ticket counters, and security counters.

TABLE 3-9 DATA OBTAINABLE FROM AIRPORT AUTHORITY OR AIRLINE

Airport Layout Dimensions
Flight Schedules
Total Passenger Flows (Arrival, Departures, Transfers)
Parking Lot Usage (From Toll Information)
Facility Information
Location
Schedule
Employee Information
Number
Work Shift Schedule
Employee
Bus/Rapid Transit Schedules
Percent of Pre-ticketed Passengers

In addition, human observers are needed to note and record significant or unusual events that the monitoring aids would be unable to detect. One such activity is the conduct of surveys. Surveys are useful to provide information for categorizing passengers in terms of trip objectives, number of visitors accompanying or meeting the passenger, personal habits, etc. The surveys should be conducted in a manner that would not interfere with the traffic flows or impinge on the privacy of the passenger.

One survey technique is to hand the passenger a questionaire card as he enters the landside system (either arriving at the parking lot or curbside or entering at the gate). The card contains information such as a number, time, location, etc. The card, filled out by the passenger, is picked up at a key location in the airport such as the ticketing counter, security counter, holding room, gate, baggage claim room, parking lot or curbside. This technique allows raw data to be collected from which statistical information (distributions, averages, and variances) can be generated. This information is excellent data for comparison with simulation derived statistics for validation purposes.

Another survey technique is to hand the passenger a long, form survey sheet, either at the parking lot or in the aircraft, for completion and return. This technique is less useful in terms of flow time statistics but it can provide information such as number of visitors, number of passengers in a group, amount of baggage, destination, germane personal habits, and suggested improvements in airport service.

The data collection program provides all the raw data needed for input to the simulation model and, more importantly, for validation of the simulation model output.

3.4 FORMULATION OF MATHEMATICAL MODELS

The computer simulation methods considered in this analysis are accounting models and time oriented simulation models[4].

3.4.1 Accounting Models

Accounting models are deterministic models which operate under invariable rules and do not introduce randomness in the calculations. An example is a population counter model which moves groups of individuals 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 departure 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 the service times at any facility are fixed for any arrival rates. The basic output of this model is the occupancy of given areas as influenced by the flight schedule.

Other accounting models may give averages of delays based upon fixed service times. If the demand exceeds the capacity at a given facility, the newly arriving groups are held back until the server is free; the delay is recorded. In this type of model no variation of dynamics, such as corridor occupancy determining walking speed is simulated. The only passenger interaction occurs when servers are occupied and the passenger must wait.

3.4.2 Time Oriented Models

This type of simulation attempts to reproduce existing situations at a detailed level either by the continuous solution of dynamic equations expressing a relationship between units or by generating random operating times which have the same distribution as the process being simulated. The first type of simulation might involve relationships such as the car-follower law. In this relationship, the acceleration of a car is related by a differential equation to its separating distance from the preceeding car, and the speeds of the two cars. The relationship is evaluated as a function of time. Motions of all vehicles in such a system are described in part by using this law and in part by programmed reactions to the physical environment which is simulated. The second type uses queueing models. Probability distribution functions are used to describe arrival patterns and service processes. Inputs and outputs of this type of model are shown in Figure 3-2 and a description of the computation for a single server is shown in Figure 3-3.

The input arrival distribution is described in terms of the interval between successive arrivals. These vary stochastically, requiring a probability density function, which forms the basis for random number generation, for computing the times of arrival at the service facility. The mean arrival rate, which may be fixed or a function of time, is part of the expression of the probability density function of inter-arrival times.

Service facility time distributions are also specified by a probability density function and require a mean service rate to generate the random service times.

The queueing discipline is a description of the relationship between the queueing 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 queueing discipline determines which is selected.

The reneging frequency is the probability density function which describes the tendency for a passenger to abandon a line due to its excessive length and seek another line, or perform another function.

Since time-oriented simulation models have the capability of completely describing the detailed activities of the airport, that type was chosen over the accounting models as the most appropriate method for later studies.

3.5 COMPUTER MODEL REQUIREMENTS

The minimum requirements for airport landside computer models are:

> The computer model must be based on a mathematical model realistically representing the detailed landside traffic activities of an airport (see Section 3.4)

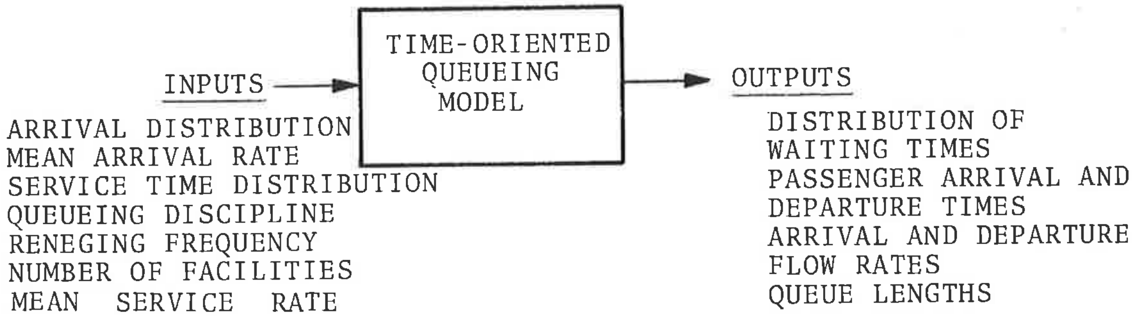


Figure 3-2 Typical Inputs and Outputs of a Time Oriented Queueing Model

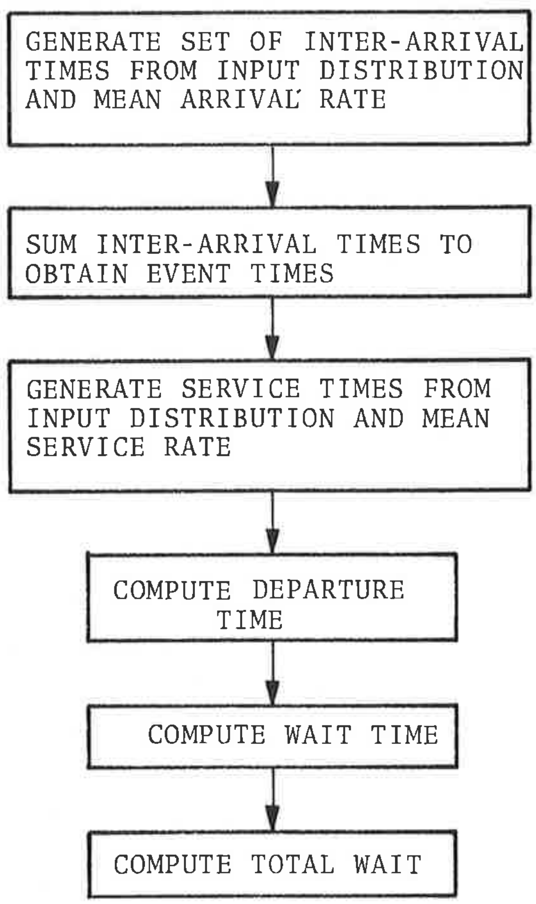


Figure 3-3 Computation of Waiting Time in a Single Channel Service Facility

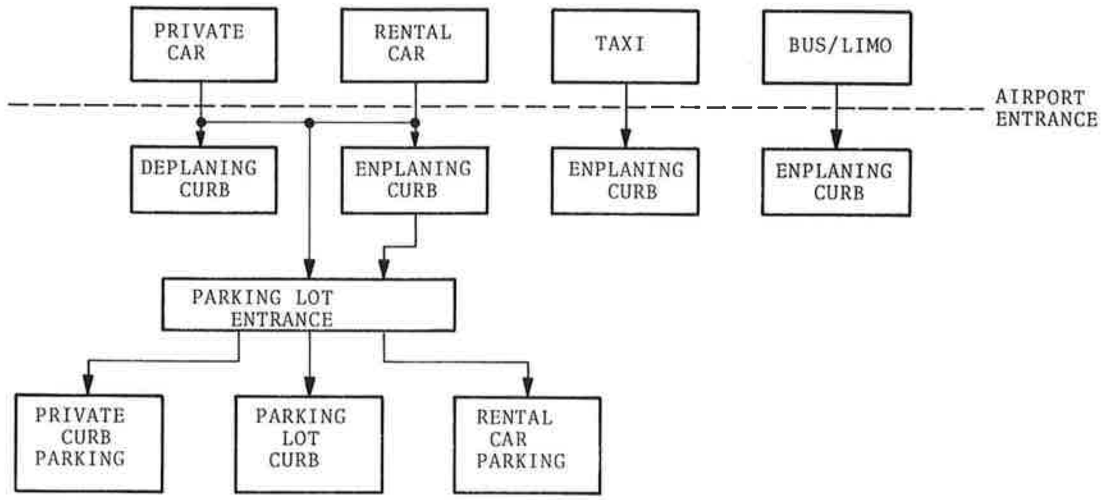
- The computer model must be formulated in a generalized manner so as to be completely site independent
- The computer model must be formulated to allow the local airport site and associated conditions to be specified by input data
- The computer model must output measures of airport landside level-of-service (see Section 2.3)
- The computer model should be programmed in a program language convenient for simulation purposes (see Section 3.6.2)

3.6 FORMULATION OF COMPUTER MODELS

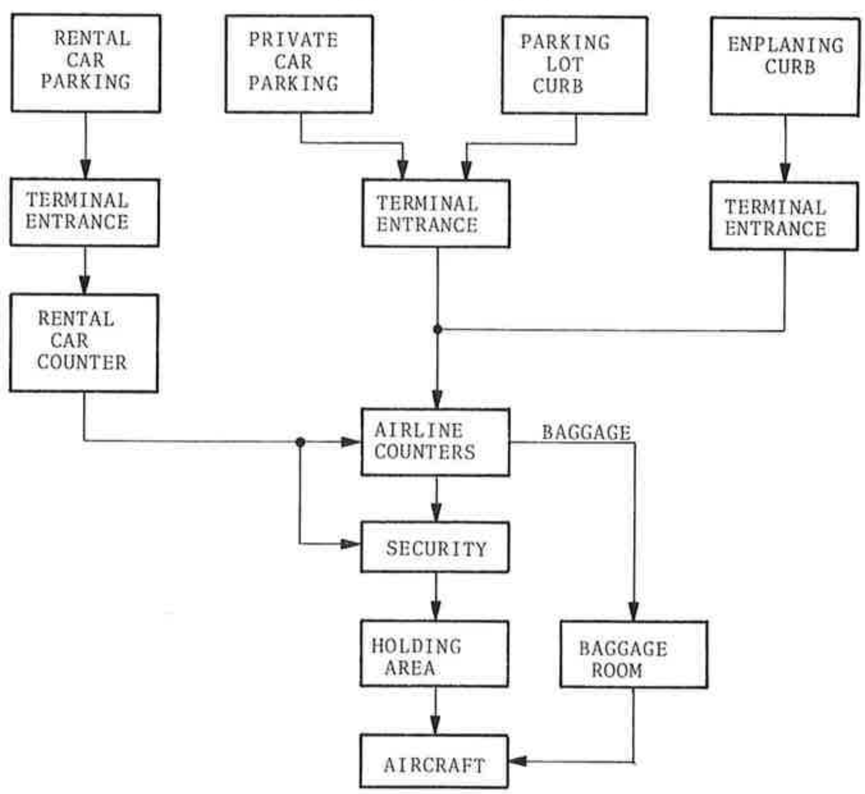
3.6.1 Computer Program Logic Flow

The airport landside computer model should be constructed following an airport landside functional flow diagram similar to that shown in Figure 2-2. The model should be built in a series of program modules, inter-connected to functionally represent the airport landside system.* Figures 3-4 and 3-5 illustrate typical flow diagrams for vehicular and passenger flows in the landside system. Figure 3-4a illustrates the vehicular time/distance flow diagram for enplaning passengers. Time/distance flow for an enplaning passenger are shown in Figure 3-4b. Figure 3-5 shows similar information for deplaning vehicles and passengers. Each line connecting blocks in the time/distance diagrams represents the distance between each activity and, depending on the passenger velocity distribution, a transit time distribution can be computed. Each of the facilities has a service time distribution associated with it. For a given passenger demand, an arrival pattern can be computed to establish facility waiting times and queue lengths. Delay distributions can then be calculated from a knowledge of the mean transit times.

*This procedure is similar to that presented in Ref. 5.

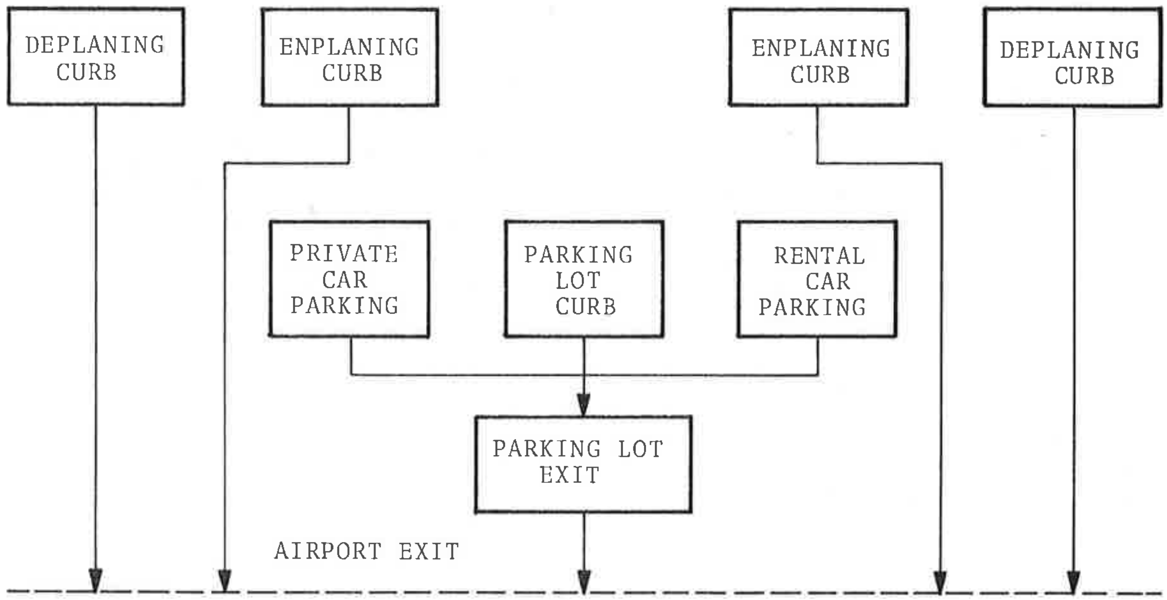


(a) Vehicular

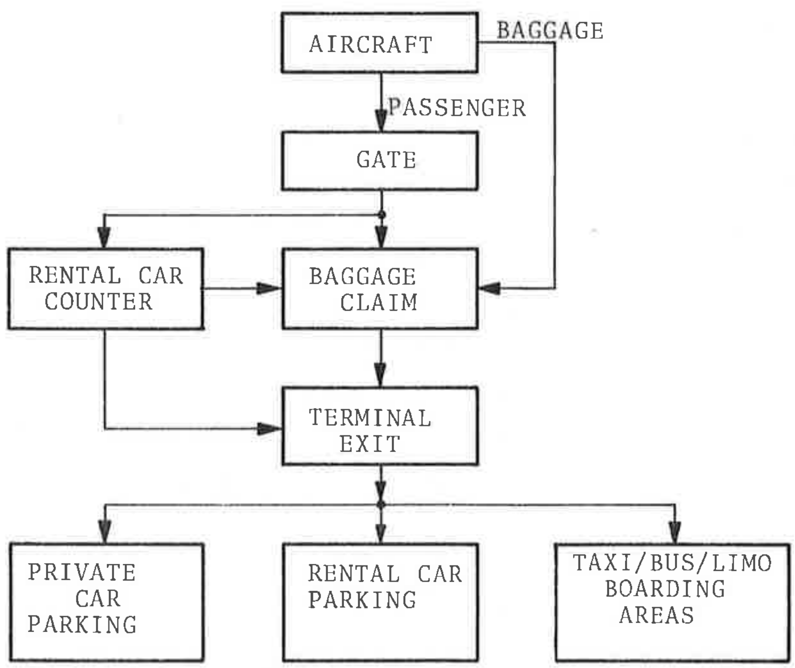


(b) Passenger

Figure 3-4. Time/Distance Flow Diagrams (Enplaning)



(a) Vehicular



(b) Passenger

Figure 3-5. Time/Distance Flow Diagrams (Deplaning)

To illustrate the procedures of time flow simulation,* consider the situation of a deplaning passenger (see Figure 3-6). Only service and transit times are presented. In addition, the distribution is described in terms of minimum and maximum times. Assume that the flight arrives at the gate and opens the door at 6:30 PM with 140 passengers leaving the aircraft. The deplaning process takes 7 minutes assuming passengers leave the aircraft at an average of one every 3 seconds. Thus, the first passenger would leave at 6:30:03 and the last passenger at 6:37:00. Assuming a transit time distribution between the aircraft and the terminal of 20-30 seconds, the first passenger arrives at the terminal building between 6:30:23 and 6:30:33 PM. Now assume that the first passenger proceeds to the baggage claim room. The transit time takes between 120-180 seconds, so that he arrives there between 6:32:23 and 6:33:33.

The arrival of the passenger bags is now the determining time parameter for most of the passengers. Bag arrival is computed based on:

1) The average unloading time per bag,
2) The capacity of bag cart,
3) The time distribution to move bags from aircraft to bag claim facility,
4) The time required to transfer bags from car to bag claim facility.

Assuming an unloading time of 2.5 seconds/bag, a cart capacity of 60 bags, a cart drive time of 70 ± 5 seconds and a cart-to-claim-facility transfer time of 1.5 seconds/bag (assuming an average of 1 bag/passenger), three cards containing 60, 60, and 20 bags, respectively are needed. The first cart is filled in 2 minutes, 30 seconds (6:32:30), and arrives at the bag claim facility between 6:33:35 and 6:33:45. Applying the transfer rate of 1.5 seconds/bag, the bags for the first cart are available in the facility

*This procedure is similar to that presented in Ref. 6.

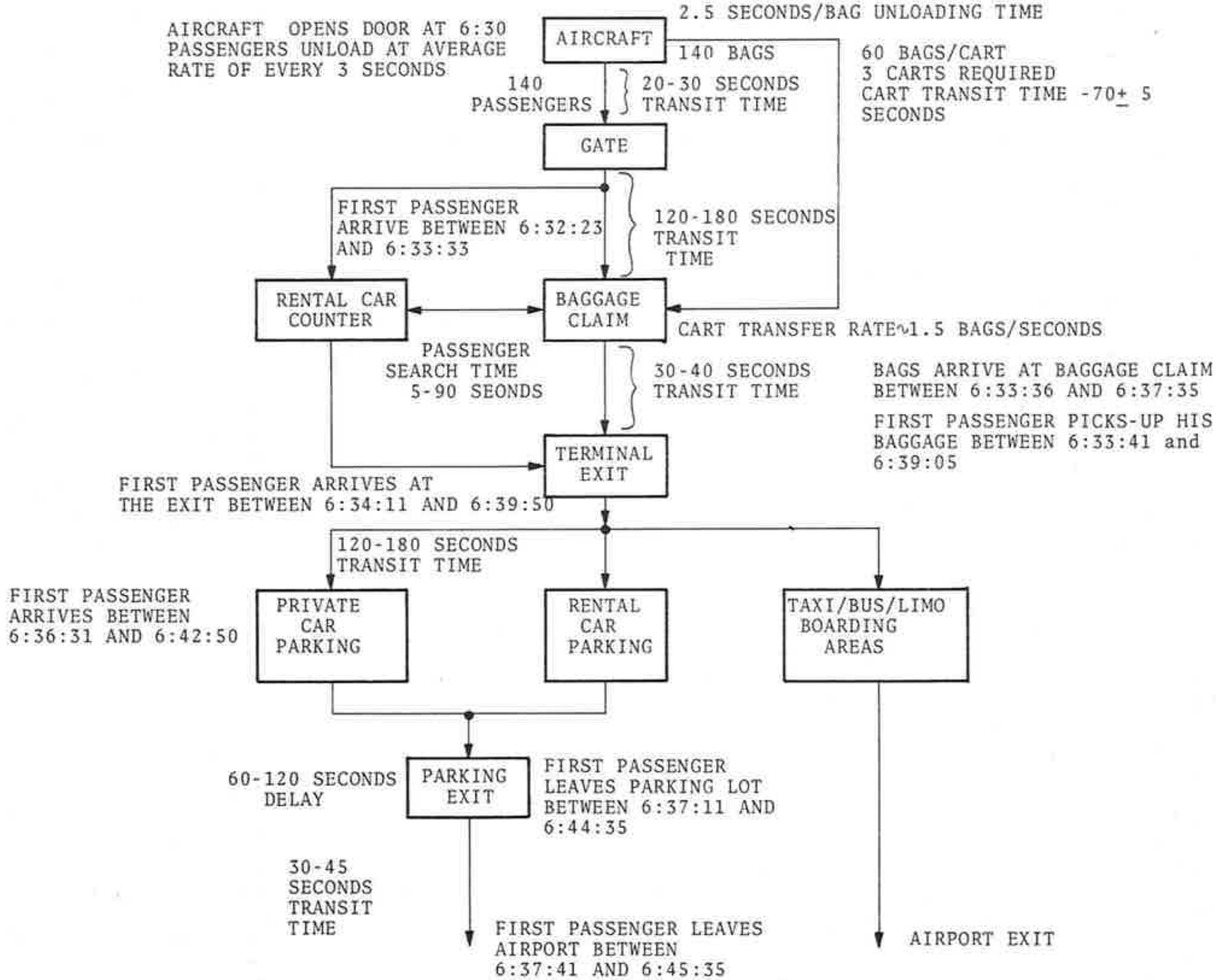


Figure 3-6 Illustrative Time Flow Analysis

between 6:33:36.5 and 6:35:15. Similarly, the second cart is filled at 6:35:00; and arrives at the bag claim facility between 6:36:05 and 6:36:15. The bags from the second cart are transferred to the bag claim facility between 6:36:06.5 and 6:37:45. The last cart is filled at 6:35:50 and arrives at the bag claim facility between 6:36:55 and 6:37:05 and 6:37:05 and the bags are transferred to the bag claim facility between 6:36:56.5 and 6:37:35.

Since the first passenger arrives at the bag claim facility at 6:32:23 at the earliest, the passenger delay at the bag claim facility can vary from a minimum of 1 minute 18.5 seconds to a maximum of 6 minutes 42 seconds, assuming a passenger bag-search-time range from 5 to 90 seconds which, in turn, depends on the number of bags. Thus, the passenger will pick up his bag at the baggage claim between 6:33:41.5 and 6:39:05.

Leaving the baggage claim facility, the passenger walks to the terminal exit and, with a transit time ranging from 30-35 seconds, arrives at the exit between 6:34:11.5 and 6:39:50. He then walks to the parking lot (assume 120 to 180 seconds) and arrives between 6:36:11.5 and 6:42:50; enters his automobile and leaves the parking lot (delayed slightly by a queue at the toll gate, assumed as 60-120 seconds) between 6:37:11.5 and 6:44:50. He leaves the airport between 6:37:41.5 and 6:45:35 PM, assuming the transit time is between 30 and 45 seconds.

Thus, the total transit time elapsing between leaving the aircraft and leaving the airport varies between a minimum of 7 minutes 41 seconds, and a maximum of 15 minutes 35 seconds. The maximum delay, therefore, is 5 minutes 35 seconds, determined on the assumption that the average time for a passenger to proceed from the aircraft to the airport exit, in the absence of queueing, is 10 minutes.

3.6.2 Simulation Language

Technical problems must be described in a scientific programming language such as Fortran to be solved by digital computers. However, Fortran does not have the necessary structure flexibility for simulation problems. There are two basic special purpose languages that have been designed to meet the needs of simulations[3]. They are SIM Script and General Purpose Simulation Language (GPSS). Of the two, GPSS seems to be more suitable since it is relatively easy for system designers, who are not necessarily expert programmers, to learn and to use.

The simulation language must be carefully considered in the light of the computer model requirements and the study objectives. For example, the program could consist of GPSS for simulation purposes and, to improve the program efficiency, Fortran for computations and possibly input and output purposes.

3.7 SIMULATION EXPERIMENTS

It may take many simulation runs to understand the relationships involved in a system. For example, to understand the sensitivity of passenger delay to demand it is necessary to run a set of simulation experiments using several demand scenarios. The simulation study, therefore, should include a set of simulation experiments[3]. Each experiment is a collection of all simulation runs of one particular system operating under one set of conditions. A run is a single execution of one experimental configuration, and it provides a set of observations. An observation is a single simulation measurement of a system variable. The experiment statistically summarizes the set of observations since the simulation model introduces stochastic variables into the simulation. Thus, the output variables which measure the airport landside level-of-service are random variables.

3.8 VALIDATION

Validation of the airport landside simulation consists of determining the degree of agreement between the simulation program output data and the corresponding quantities obtained by observations. Mean values, variances and distributions may be tested against the null hypothesis,

$$H_o\text{: Field quantity = simulated quantity}$$

The measures of effectiveness to be considered for this type of simulation are: flows, queue lengths, delay times and occupancies. These are compared for specified simulated functions such as parking lot entrances and exits, curbsides, ticket and gate counters and baggage claim areas. Mean values, variances and distributions are tested by the use of the student's t, F Test, and U test.

The t test is used to test the hypothesis that there is no statistically significant difference between the mean of the field observations and that of the simulation. The t statistic is,

$$t = \frac{(\overline{X}_1 - \overline{X}_2)}{S_p^2 \sqrt{2/N}}$$

where $\overline{X}_1$ and $\overline{X}_2$ are the two sample means,

S_p^2 is the pooled variance,

N is the sample size.

The statistic has a student's t distribution when the underlying distributions of the X's are normal.

The F test, which tests the variance, is given by the following statistic for the case of equal sample sizes

$$F = \frac{\frac{N}{N-1}(\overline{X}_1 - \overline{X}_2)^2}{\sum_{j=1}^{N} (X_{1j}^2 + X_{2j}^2) - N(\overline{X}_1^2 + \overline{X}_2^2)}$$

where the j's refer to each observation.

The U test is used to determine whether the two sets of samples arise from the same population. This is performed by ranking the two samples, summing ranks and computing a statistic which is normally distributed.

4. REVIEW OF EXISTING SIMULATION MODELS

This section describes seven airport landside computer simulation models.

1. The Bechtel Simulation Model
2. The Tippetts-Abbetts-McCarthy-Stratton (TAMS) Simulation Model
3. The Port of New York Authority (PONYA) Simulation Model
4. The Massachusetts Institute of Technology (MIT) Simulation Model
5. The Battelle Simulation Model
6. The University of Waterloo Simulation Model
7. The Canadian Ministry of Transport Calgary Model

The descriptions are summaries prepared from information supplied by the respective organizations.

4.1 BECHTEL SIMULATION MODEL

This model is a comprehensive, time-oriented event simulation model programmed in GPSS-5 and developed on the IBM 360/65 computer. It mathematically models the behavior of people between the airport boundary and the arrival/departure gates, translating the controlling flight schedule data into passenger flows, passenger transit time statistics, and queue lengths at service counters. However, the program is company proprietary so the model description as obtained is sketchy in some areas.[6,7]

The input data used in the Bechtel model has been roughly divided by Bechtel into three major areas:

Demand forecast data
Processing time data
System configuration data

Table 4-1 presents a further breakdown of the input data needed to operate the program.

The output data used in the Bechtel Model has been roughly divided by Bechtel into ten major areas including:

1. Enplaning/deplaning passenger attributes
2. Passenger statistics
3. Airline counter statistics
4. Aircraft gate statistics
5. Baggage claim statistics
6. Airport road statistics
7. Airport parking area statistics
8. Airport curb area statistics
9. Employee statistics
10. Miscellaneous statistics

Table 4-2 presents a further breakdown of the output data possible from this program.

Model Description

The Bechtel airport simulation model consists of three major model groups (Figure 4-1) which are:

Surface Transportation Group
Terminal Group
Gate and Airside Groups

Surface Transportation Group

The surface transportation group consists of one program (Figure 4-2) which is designed to simulate long-term parking activities. The program accepts statistical inputs for car arrival rates, duration of stay, and the average daily long-term parking load. The program distributes the daily load in a uniformly random fashion. A 10 day load average can be run over a simulation period of up to 100 days to generate the frequency distribution of vehicles.

TABLE 4-1 INPUT DATA (BECHTEL MODEL)

a) Demand Forecasts

1) Number of passengers (peak hour/annual)

2) Number of air carrier flights (annual)

3) Flight departure/arrival schedule

4) Number of airlines

5) Percent of passengers originating/terminating/transferring

6) Number of visitors per passenger

7) Number of employees

8) Baggage per passenger

9) Percentage of passengers pre-ticketed

10) Number of passengers per flight per aircraft type

11) Number of rental car companies

12) Number of vehicles (passengers, visitors, and employees) and the types of vehicles

13) Passengers/visitors/employees per vehicle

14) Bus and limo schedules

15) Employee arrival/departure distribution

b) Processing Time

1) Service times (ticket counters, check-in counters, car rental counters, bus/limo counter, baggage claim, security, etc)

2) Transit time (parking area to and from terminal entrance, terminal entrance to and from service counter, service counter to and from holding room, holding room to and from aircraft, point to point travels).

TABLE 4-1 INPUT DATA (BECHTEL MODEL) - CONTINUED

3) Baggage handling time (check-in counter to baggage make up room, baggage sorting and handling, transport to and from aircraft, aircraft loading and unloading times, load baggage onto claim rack).

c) System Configuration

1) Facility descriptions

Parking areas (main, terminal, rental car, employee)

Curbside areas

Terminal building

2) Traffic routing within airport complex (roadways, sidewalks, corridors, etc.)

3) Transportation modes within airport.

4) Service capabilities

Equipment distribution

Crew make-up

Service times

TABLE 4-2 OUTPUT DATA (BECHTEL MODEL)

Enplaning/Deplaning Passenger Attributes

1) Airline, flight number, gate number, aircraft type, arrival or departure times

Modes of surface transportation

3) Quantity of baggage

4) Time of arrival to and departure time from airport (also time of arrival at and departure from terminal entrance)

Passenger Statistics

1) Quantity of enplaning/deplaning passengers processed through terminal & model in a given time frame

2) Flow time through terminal and model

Quantity and destination of passengers in process at end of given time frame

4) Number of passengers missing flight

5) Model waiting times (associated with bus/limo stops)

Airline Counter Statistics (Ticket, Check-in, Car Rental, Bus/Limo, and Other

1) Number of passengers processed

2) Number of passengers processed at no wait

3) Average/maximum passenger waiting time

Aircraft Rate Statistics

1) Number of passengers processed

2) Average passenger waiting time

3) Maximum number of passengers built up prior to opening boarding gate

Baggage Claim Statistics

1) Number of passengers claiming baggage

2) Average time for passenger to claim baggage

3) Maximum number of passengers waiting at one time

TABLE 4-2 OUTPUT DATA (BECHTEL MODEL) - Continued

Airport Road Statistics
1) Number of vehicles entering airport
2) Number of vehicles exiting airport
3) Average time vehicle spends on road
4) Maximum number of vehicles on road
Airport Parking Area Statistics
1) Number of cars entering
2) Number of cars exiting
3) Maximum number of cars in area
4) Average waiting time for cars to enter/exit (main and employee parking)
5) Maximum number of cars waiting to enter/exit at any one time (main and employee parking)
Airport Curb Area Statistics
1) Number of vehicles (bus, limo, taxi)
2) Maximum number of vehicles at curb at one time
3) Average time vehicles spend at curb
Employee Statistics
1) Number of employees entering/leaving airport in given time frame
2) Flow time through model
3) Quantity and destination of employees in transit at end of time frame
4) Number of employees/company/located at various work stations
Miscellaneous Statistics
1) Time vistors spend in terminal
2) Quantity of baggage loaded/unloaded for each flight

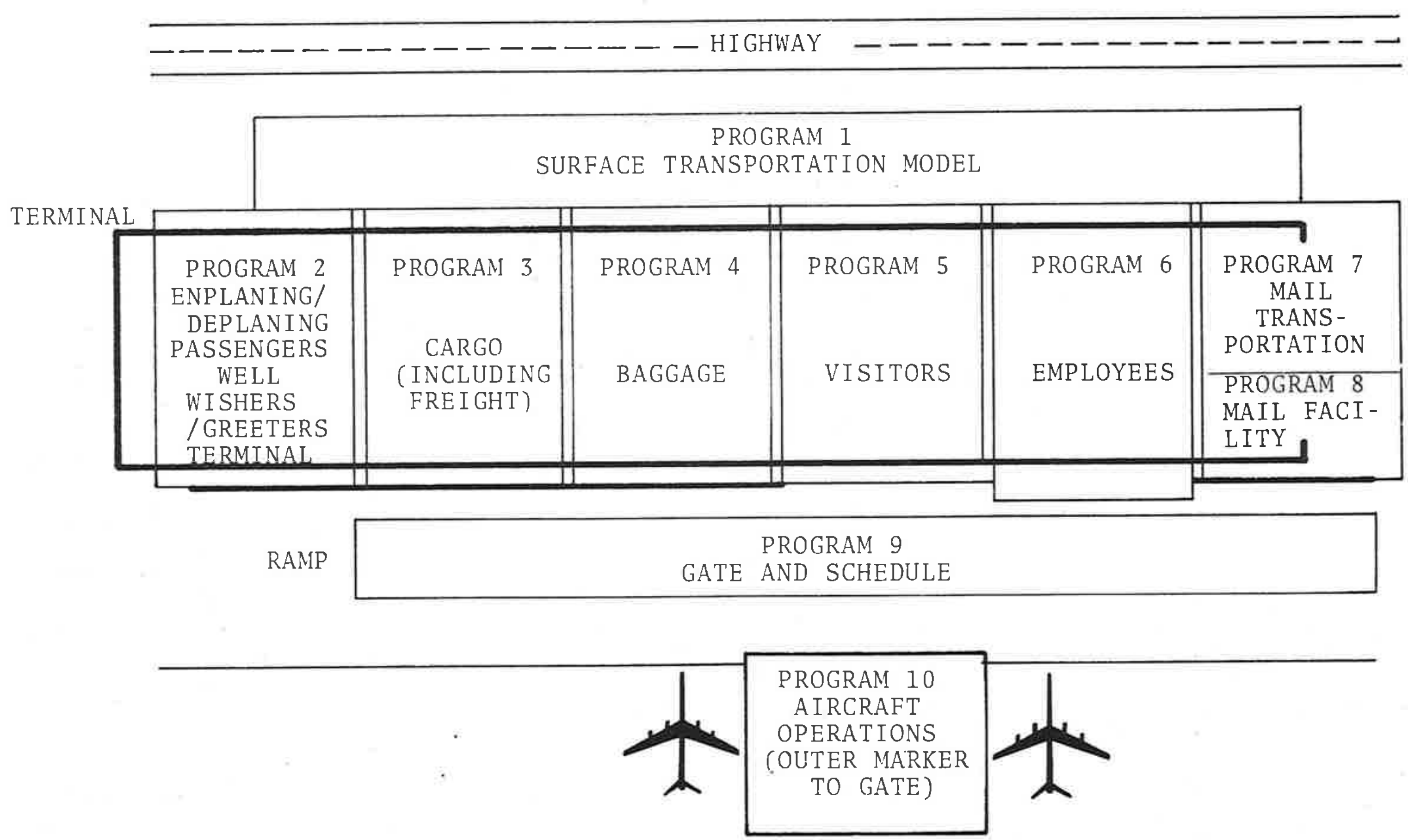


Figure 4-1. Computer Model Library

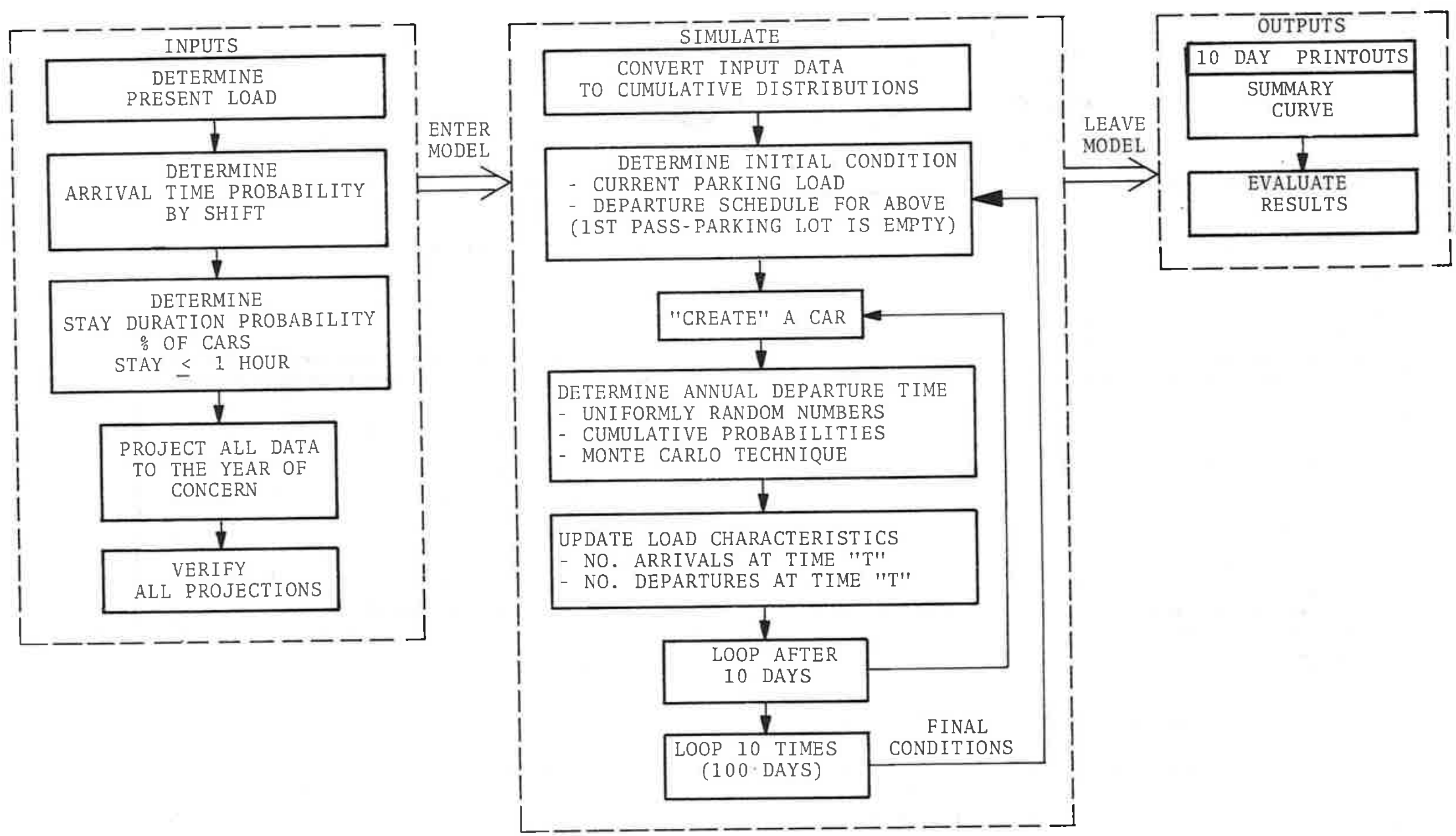


Figure 4-2 Parking Simulation Model

Terminal Groups

The terminal group is the most complex model of the Bechtel major model groups (Figure 4-1). It consists of seven programs describing most passenger and baggage activities including deplaning passenger movements, enplaning passenger movements, and vehicular transportation movements. Deplaning passenger activities include all passenger movements, and all possible combinations of movement, from the aircraft door opening to the terminal exit (Figure 4-3). Enplaning passenger activities include all passenger movements, and all possible combinations of movements, from the terminal door to boarding the aircraft (Figure 4-4). Vehicular transportation activities include all vehicle movements from the airport highway to the terminal door (Figure 4-5).

All segments of this model are connected (Figure 4-6) so that interactions are simulated throughout the entire system. The activities associated with security, which Bechtel is presently incorporating, are not shown. Deplaning passengers are processed out of the arriving airplane according to a chosen time distribution and proceed into the terminal. A choice of paths through the terminal is made, based upon passenger requirements. Movements through the terminal are then simulated. Individual walking speeds and transit times based on distributions are incorporated in the model. Passenger requirements are based upon statistical distributions. Passengers may be routed to the baggage claim area, or directly to a parked car or to a car rental counter. If the passenger is transferring, the routing may be to a waiting room or ticket counter.

Enplaning passengers are given three choices of routes based upon predetermined distributions. The routing is either to a car rental or airline ticket counter or directly to a waiting room. The delays encountered at the counters are calculated on a per passenger basis. The routing continues through a security checkpoint to the airplane gate. Delays encountered throughout the airport are computed.

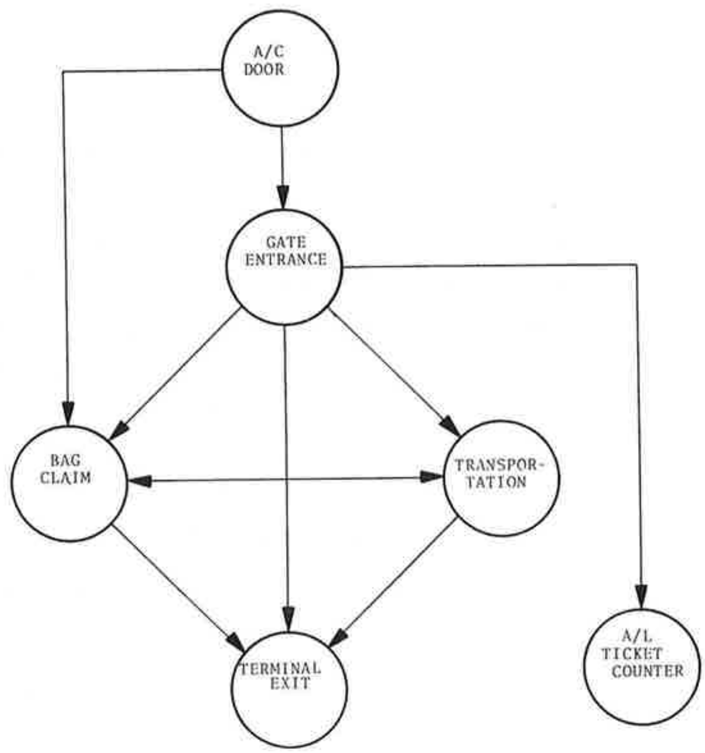


Figure 4-3 Disembarking Passenger Flow Inside Terminal

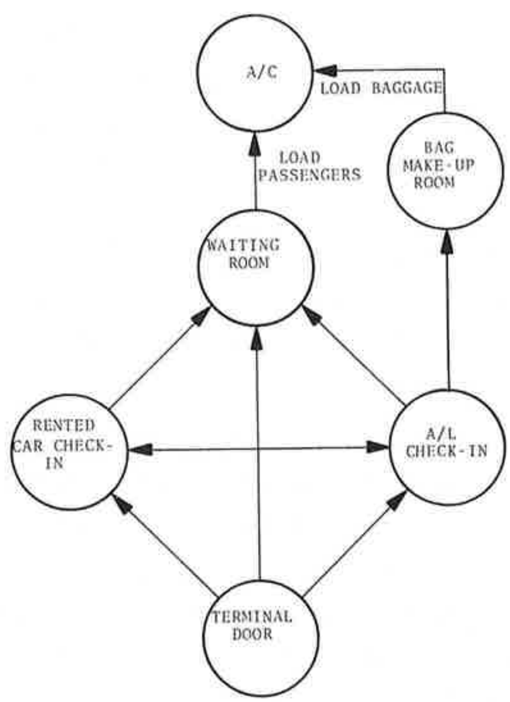


Figure 4-4 Embarking Passenger Flow Inside Terminal

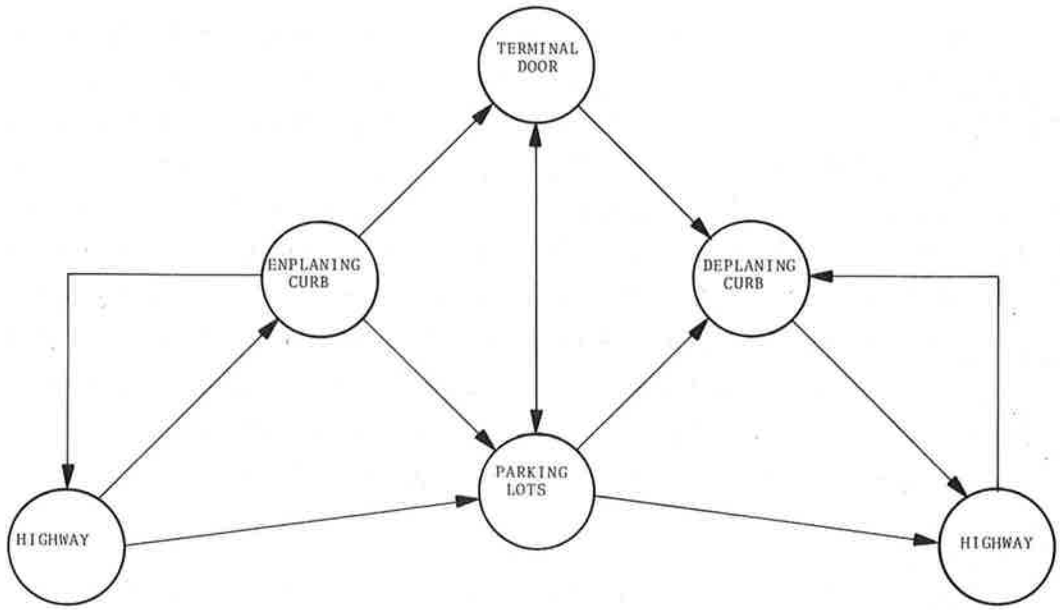


Figure 4-5 Vehicular Transportation Network

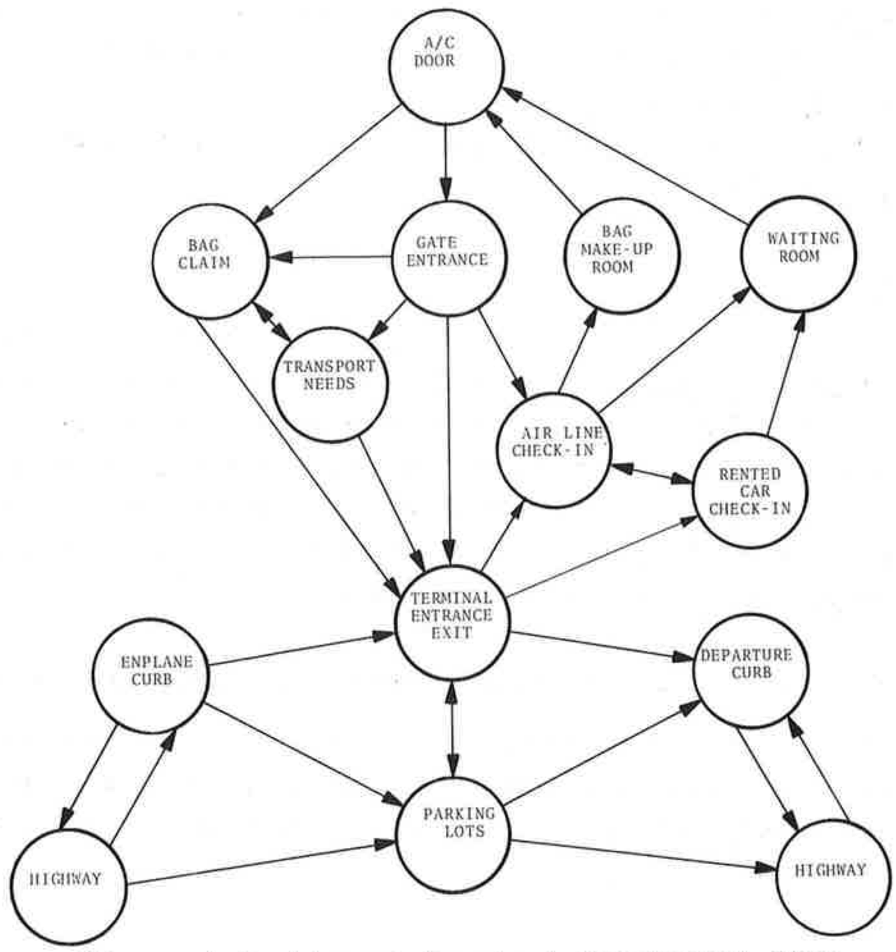


Figure 4-6 Airport Terminal Functional Flow

The vehicular transportation portion simulates both personal and vehicular movements from the highway to the terminal door. Depending upon distributions, a vehicle may proceed to the parking area, the deplaning curbs or the enplaning curbs. The vehicles are associated with passengers and transit times for individuals may be computed. Various combinations of movements between the parking lot are simulated based upon distributions. Among these are one passenger providing valet service for another, or a greeter proceeding to the parking lot first and later to the curbside. All modes of transportation are considered, including buses, limousines, rented cars, taxis, and private vehicles.

Gate and Airside Group

The gate and airside group consists of two programs. The gate schedule model is designed to generate arrival and departure schedules, assign aircraft to the terminal gates, and distribute passengers according to time and location based on input flight and terminal gate data. Basically, the model creates the airport's total daily flight schedule of arrivals and departures using annual traffic data.

Summary

This model is a time-oriented, queueing event simulation model that can dynamically describe and statistically summarize the passenger flows, flow transit time distributions, occupancies, and queue lengths. It does not, at present, include passenger delay distribution capability, but probably can be extended to include it. Validation efforts have not yet been sufficient to provide high confidence in the validation results.

4.2 THE TIPPETTS-ABBETT-McCARTHY-STRATTON (TAMS) SIMULATION MODEL

The TAMS landside model[8] consists of a terminal model and a roadway model that describe the traffic behavior between the airport boundary and the gate. These models are programmed in GPSS-II on IBM 360 equipment.

Terminal Model

The terminal model is a time oriented, queueing event simulation model designed for both international and domestic airports. The functional description of this model can be conveniently presented in terms of deplaning and enplaning passengers.

Deplaning Passengers - The airline schedule is used to generate the probable arrival times and the number of passengers deplaning from an aircraft. The deplaning passengers are initially aggregated into passenger groups. Each passenger group is randomly assigned a walking speed according to an input distribution. Transfer passengers are separated and proceed to a transit lounge to await the departure of their flight. Arriving international passengers proceed to health and immigration check points. These passengers then proceed to the baggage claim area. Arriving domestic passengers without visitors proceed directly to the terminal exit or to the baggage claim area. Domestic passengers with visitors dwell in the holdroom for a short period before leaving for the terminal building exit or baggage claim area. At the baggage claim area both international and domestic passengers wait to pick up their baggage. The computer waiting time is different for international and domestic passengers but in both cases is based on the assumption that the probability of claiming baggage at any given time is equal to the proportion of the flight's baggage that is in the baggage claim area. After claiming baggage, the international passengers proceed immediately to the customs area, selecting the shortest queue. After clearing customs, they meet greeters and after a short dwell time proceed either to the curb or to the parking garage.

Enplaning Passengers - Passenger groups enter the concourse with their visitors either from the curb or from the garage. They are randomly assigned walking speeds from the walking speed distribution. A passenger group proceeds to the ticket check-in, selecting the shortest queue. For ticket check-in, the processing time is randomly selected from a service time distribution. After check-in, international passengers are randomly assigned a time to report to emigration. At emigration, processing times are randomly assigned according to a distribution. Here international passengers take leave of their visitors. The passenger group then proceeds to a holding room and waits until the flight time. Domestic passengers take leave of their visitors at boarding time.

Input/Output Data - The input data used to simulate the movements of persons in the terminal model is shown in Table 4-3. Table 4-4 presents the output data. Figure 4-7 illustrates the time deplaning passengers require to reach the curb after aircraft arrival at the gate[9]. The distributions of these time intervals vary depending on processing times, and are shown for both international and domestic passengers. As shown, the time for domestic passengers is less since they do not have to go through health, immigration, and custom formalities. The discontinuity in the domestic distribution is due to the difference in clearing times between passengers without baggages and those with bags. Passengers without bags clear in 6 minutes but passengers with bags have to wait at least 10 minutes for the first bag to arrive at the baggage claim area.

Roadway Model

The roadway model is also a time-oriented, event simulation model which generates a variety of vehicles (modes of transport) according to user as shown in Table 4-5.

Enplaning Passengers - Passengers are divided according to their time of entry into the roadway system (Figure 4-8) and then further divided into passenger groups according to a group size distribution. They are then further divided according to a model split distribution.

Private Automobiles - Passengers and visitors using the private auto mode are assigned vehicles and routed as shown in Figure 4-8. Only passengers arriving in the private auto mode are assumed to have visitors, and these are assigned on the basis of a distribution determined from survey data. The number of passengers and visitors in each group is then summed to determine

TABLE 4-3 INPUT DATA FOR TAMS TERMINAL MODEL

Aircraft Parameters

1) Number of doors
2) Load/unload rate
3) Load time before departure

Passenger Parameters

1) Size distribution (international and domestic)
2) Walking speed distribution
3) Accompanying visitors for enplaning/deplaning passengers (international and domestic)
4) Baggage per passenger (international and domestic)

Facility Parameters

1) Escalator/elevator speed and occupancy
2) Service time distributions data
3) Baggage claim rates data
4) Terminal physical layout and dimensions

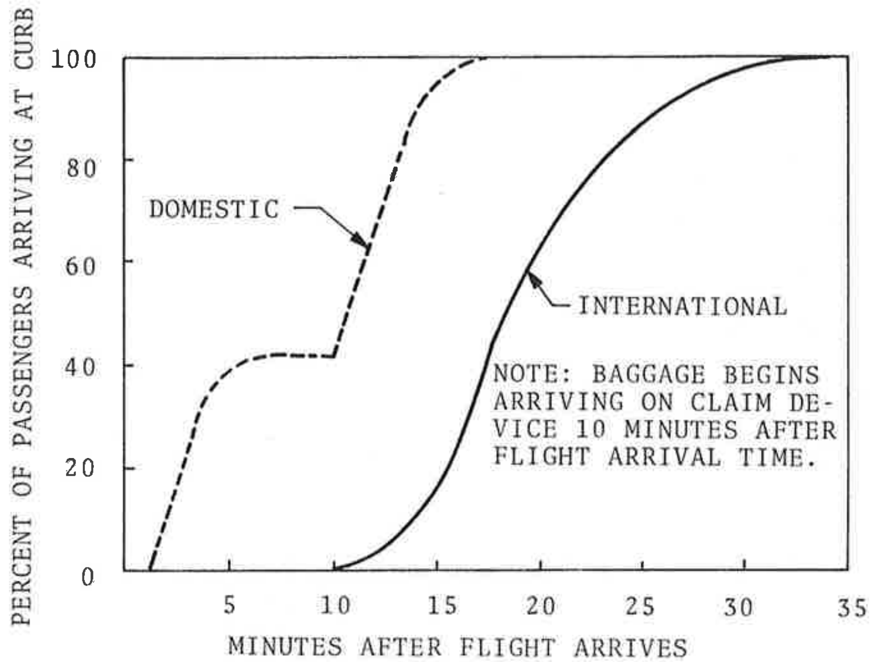
TABLE 4-4 OUTPUT DATA FOR TAMS TERMINAL MODEL

Queue Lengths Statistics at Each Facility

Accumulation (Occupancy) Statistics at each Holding Area

Utilization Statistics at Each Facility

Transit Time Distributions



Reference 9

Figure 4-7 Distribution of Deplaning Passenger Transit Times (Gate to Curb)

TABLE 4-5 AIRPORT USER AND AVAILABLE MODES OF TRANSPORT

User	Mode
Enplaning Passengers and Visitors and Deplaning Passengers and Visitors	Private Auto Taxicab Limousine Rental Car Public Bus Airline Bus
Terminal Area Employees	Private Auto Jitney Public Bus Company Bus
Sightseers and Salesmen	Private Auto
Service	Truck

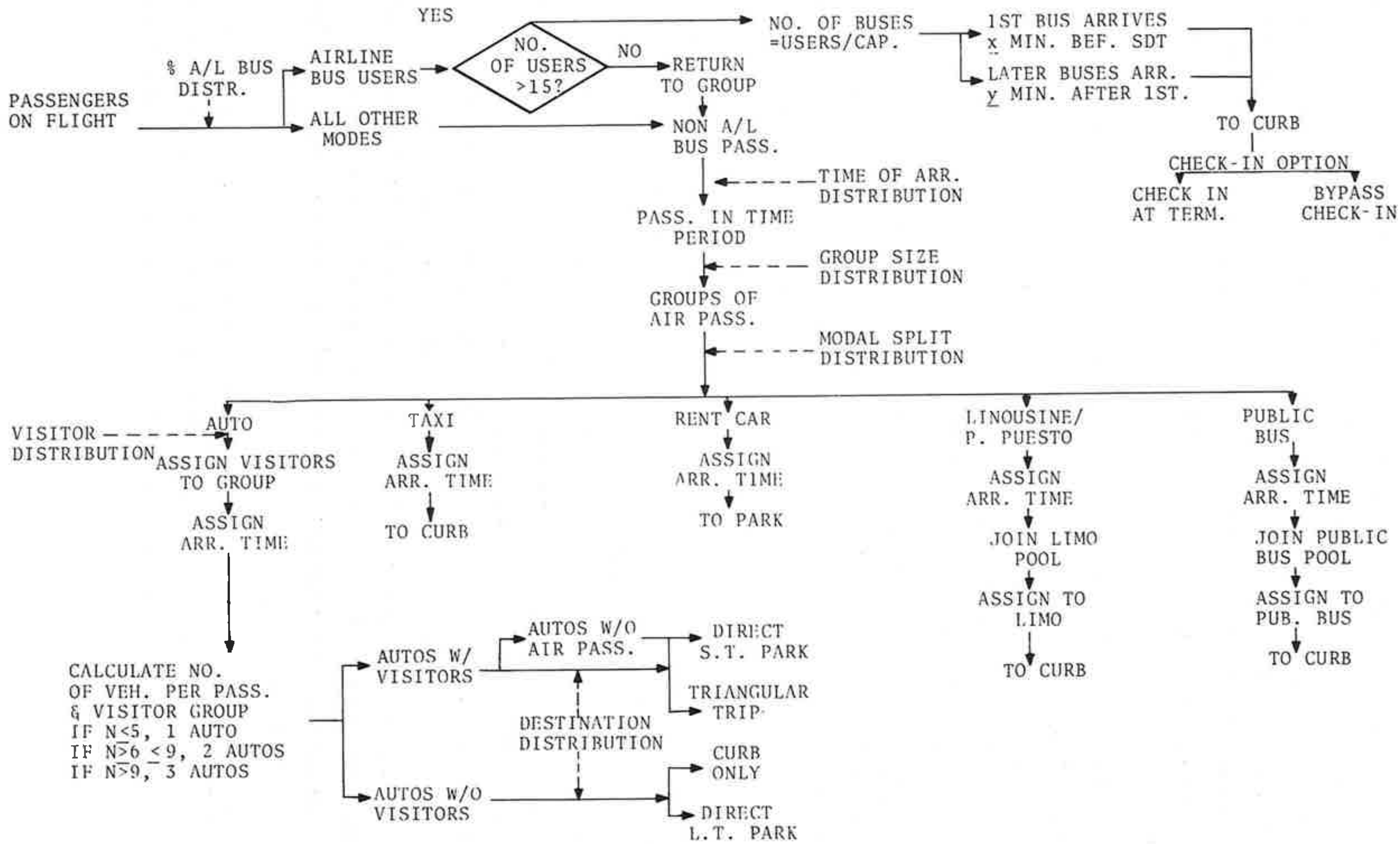


Figure 4-8 Generation of Enplaning Passenger Trips

how many vehicles that passenger group generates. All air passengers in each group are assigned to one car, and automobiles with visitors only go directly to short term parking. Automobiles containing both passengers and visitors have a choice of short term parking or going to the curb and then parking. Those containing only passengers must go to either long-term parking or the enplane curb.

Taxicabs - Each taxi transports one passenger group to the airport and drops them off at the curb of the appropriate terminal module. After leaving the curb, a given percentage of taxis must leave the airport since, by franchise, they are not permitted to pick up passengers at the airport.

Limousines - Limousines operate on a fixed schedule predetermined on the basis of the estimated demand. Assigned enplaning passengers attempt to take the first limousine departing after their assigned arrival at the limo originating points. If it is full, the passenger waits for the next one.

If a limousine is carrying any international passengers, it takes the roadway leading to the international enplane curb, drops off its passengers at the appropriate module and then travels to the domestic curb. If a limousine has no international passengers, it is routed directly to the domestic curb, where the enplaning passengers are discharged at the appropriate terminals and any deplaning passengers who are waiting for limousine service are picked up. Finally, it is routed to the international deplaning curb to pick up passengers. Limousines leave the terminal after passing the international deplane curb or when they have reached their capacity. They stop only at modules where there is demand for their services.

Public Buses - Public buses operate on a schedule and follow a fixed path that takes them to the international enplane curb, thence to the domestic, and finally to the international deplane curbs.

Airline Buses - The airline bus transports passengers for one specific flight. These passengers are immediately split out of the total by applying a percentage distribution to passengers on the flight. If the number of passengers then assigned to the airline bus mode is less than a given number, no airline bus will be generated and passengers are reassigned to other modes. If it is greater, passengers board the bus to its capacity and more buses are generated until all passengers are accounted for. The first bus arrives at a given time before the flight's schedule departure time and subsequent buses arrive at fixed intervals after the first bus.

Deplaning Passengers - Vehicles generated to pick up deplaning passengers are generated in a manner similar to that shown in Figure 4-8 for enplaning passengers and visitors. At a given time before each incoming flight arrives at the gate, passengers on the flight are assigned to a group, mode of transportation, etc. Those passengers meeting visitors generate a number of visitors who arrive in a given time distribution before the flight is due to arrive. Again, the number of private autos generated is determined by the sum of visitors plus passengers in each group. These autos are then assigned an entry time into the roadway system and all go directly to short term parking.

Deplaning passengers assigned to the private auto mode join their visitors (if they have any) and are then assigned a way of leaving. If they do not have visitors, they pick up their car at the long term parking lot. If they meet visitors, they either go with them to short term parking or wait to be picked up at the curb.

Deplaning passengers assigned to taxi, public bus or limousine modes go directly to the curb where they wait for the appropriate vehicles to pick them up. Rental car users to directly to the short term parking area.

A percentage of deplaning passengers are also assigned to the airline bus mode. After leaving the terminal concourse, they wait at the curb for the airline bus (or buses) to depart. The buses arrive at the curb at a fixed time after the flight arrives and remain at the curb for a fixed period before departing. If any passengers assigned to the airline bus mode reach the curb after the bus has left, they are reassigned to the public bus mode.

Simulation of Vehicular Movements - The terminal area roadway network is a series of roadways and a number of interconnecting ramps. Defined points on the roadways, separated by links, are located by x and y coordinates. When each vehicle is generated, it is assigned a point of entry into the system and a destination point. The vehicle moves through the system links at the speeds assigned for each link.

If its destination is a parking lot, the simulated vehicle is stored and loses its separate identity. If it is destined for a curb point, it remains at the curb for a period of time depending on vehicle type and number of passengers embarking or disembarking. After this activity is completed, the vehicle is assigned a new destination (another curb, parking area or airport exit) and begins moving toward it.

Input/Output Data - Table 4-6 presents the model's principal output data. Table 4-7 presents a list of the principal input data needed to simulate vehicular movements.

TABLE 4-6 OUTPUT DATA FOR TAMS ROADWAY MODEL

1) Model Assignment Distribution
2) Arrival Time Distribution
3) Number of Vehicles/Passenger Group

TABLE 4-7 INPUT DATA FOR TAMS ROADWAY MODELS

Air Passenger Group Size Distribution
Arrival Time Distributions
1) Enplaning passengers and visitors
2) Visitors meeting deplaning passengers
3) Employees, sightseers, salesmen, and others
Departure Time Distributions
1) Deplaning passengers and accompanying visitors
2) Enplaning visitors
3) Employees sightseers, salesmen, and others
Modal Split Data
1) Distribution of visitors accompanying passengers into terminal (auto mode)
2) Passenger/auto mode distribution
3) Routing of transit model
4) Employee/modal splits
5) Modal schedule data
6) Modal occupancy distribution data

Summary

The TAMS terminal and roadway models are time oriented queueing models that output queue lengths, occupancy, transit time, and utilization statistics. At present, no delay time statistics are outputted. The capability of the program to be extended to handle delay distribution is unknown. No validation effort has been conducted.

4.3 THE PORT OF NEW YORK AUTHORITY (PONYA) SIMULATION MODEL

PONYA is a time-oriented, event simulation model, processing arrivals at an international airport terminal[10]. It predicts flow, delay, and facility utilization based on traffic projections, physical plans, and operational procedures and has been used to evaluate planning and operating alternatives. Figure 4-9 presents a general flow diagram for the model. The processing of international arrivals includes passenger and baggage deplaning, Federal inspection functions, baggage handling and passenger and baggage matching. The computer program is a time oriented, queueing model programmed in GPSS II and developed on the IBM 360/75. The available documentation is sketchy but is adequate for comparative purposes.

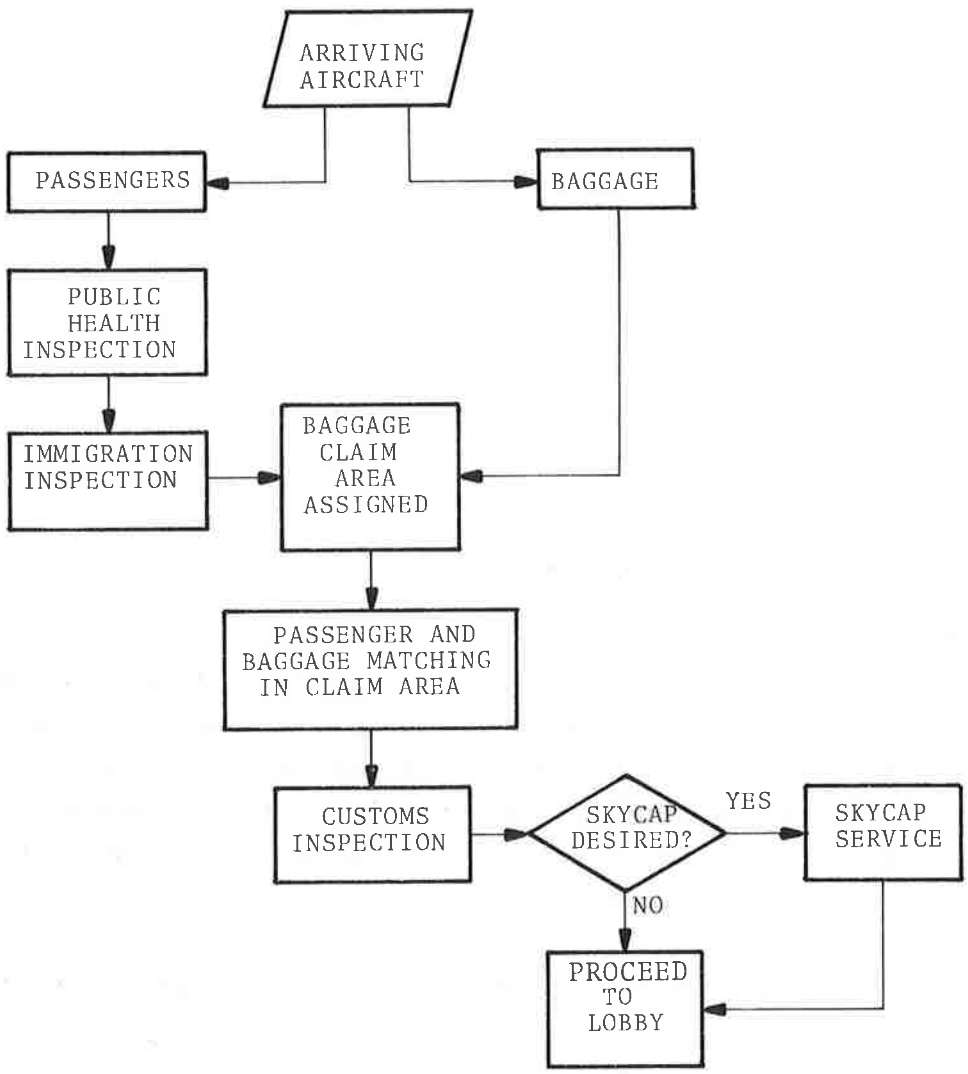


Figure 4-9 General Flow Diagram for an International Terminal

Input Data

The input data indicated in the available documentation as necessary for the PONYA model is based primarily on the intended application of evaluating operational changes at the J.F. Kennedy International Airport. The facility data is concerned primarily with the number of service facilities, that is, conveyors, needed to move arriving passengers efficiently. The passenger data is primarily concerned with passenger group sizes. The flow data is concerned with passenger and baggage arrival rates and facility processing rates. The operational data is concerned primarily with such matters as crew sizes at service facilities, and group routing. Table 4-8 summarizes the input data.

TABLE 4-8 INPUT DATA FOR PONYA SIMULATION MODEL

FACILITY DATA	
	Terminal Building Layout
	Number of Service Facilities
PASSENGER DATA	
	Passenger Group Size
	Bags/Group
FLOW DATA	
	Passenger Arrival Rates
	Baggage Arrival Rates
	Facility Processing Rates
OPERATIONAL DATA	
	Passengers/Conveyor
	Bags/Conveyor
	Group Routing Information
	Crew Size at Facility
	Airline Schedule (with Aircraft Type and Passenger Loads)
	Facility Schedule
	Gate Assignments

Output Data

The output of the PONYA model is concerned with passenger and baggage flows, waiting times, queue lengths, and utilization of the airport facilities. Table 4-9 summarizes the output data.

Summary

This is a time oriented, queueing event simulation model. At present, it is written for an international terminal, but with some simplifying assumptions it can be applied to domestic terminals. It only applies to the terminal facility itself and then only to arrivals. Some validation effort has been conducted but little information has been published.

TABLE 4-9 OUTPUT DATA FROM PONYA SIMULATION MODEL

FLOW

- Number of Passengers Processed
  1) Customs
  2) Baggage claim
  3) Immigration
  4) Public health
  5) Terminal building
- Quantity of Baggage
  1) Baggage claim
  2) Terminal building

FLOW TIME

- Waiting Times (Passenger and Baggage)
  1) Facilities
  2) Terminal building

OCCUPANCY

- Queue Lengths (Passenger and Baggage)
  - Facilities

UTILIZATION

- Facilities
- Manpower

4.4 THE MIT VTOL METROPORT SIMULATION[11]

This simulation, designed for a metroport at which vertical take-off and landing (VTOL) aircraft operate, begins with the creation of a passenger group composed of a departing passenger and accompanying well wishers. Interarrival times of these groups are based upon random number generation using a Poisson distribution. The mean arrival rate is varied as a function of time relative to time-until-flight-departure. The mode of ground transportation chosen, based upon an input distribution, determines whether or not the curbside is used. If used, the group service time is calculated based upon the number in the group. The groups then proceed into the terminal where the necessary functions of ticketing and baggage checking are performed based upon input passenger characteristics. Queue lengths and delay times are calculated for these operations. Using the input service time distributions, passengers are then routed to the waiting areas, separated from well-wishers at appropriate times, and finally passed through boarding gates.

Arriving passengers merely deplane and are joined with their greeters. A description of the baggage pick up operation was not available for study.

<u>Summary</u>

The simulation was designed to determine statistics of passenger flow through an advanced design VTOL terminal. The emphasis of the simulation is on the distribution of flows as a function of time, using queueing models for each service. The simulation is limited to a four gate airport with automated ticketing procedures. This model is site specific in that the geometry has been incorporated into the model. The model's strongest advantages are the individual treatment of the passenger and the use of distributed rather than mean service times for the services. The model in its present form is not applicable to landside analysis of existing airports. Although the model's basic approach is suitable, the extent of modification necessary to achieve this is not known. Tables 4-10 and 4-11 show the model inputs and outputs.

TABLE 4-10 MIT VTOL METROPORT SIMULATION INPUTS

1) Terminal Walking Distances
2) Arrival Rate Function
3) Group Walking Speed Distribution
4) Service Time Distributions
5) Flight Times
6) Passenger Flight Number
7) Access/Egress Mode
8) Number of Passengers in Group
9) Number of Well Wishers in Group
10) Passenger Baggage Requirements
11) Passenger Reservations, Ticket Status

TABLE 4-11 MIT VTOL METROPORT SIMULATION OUTPUTS

1) Number of Groups Arriving
2) Total Entries at Queues
3) Arrival Times for Departing Passengers
4) Arrival Times for Greeters
5) Queue Time Distributions
6) Average Time per Transaction
7) Waiting Area Occupancy Statistics
8) Queue (Maximum Contents)
9) Queue (Average Contents)

4.5 THE BATTELLE LANDSIDE MODEL

Functional Description

This model is an accounting type which calculates the daily airport population at the basic airport functions over a number of time intervals during the day. The distances between necessary elements are represented by the number of time intervals separating the elements. Figure 4-10 presents a description of this landside model.[12]

The simulation begins by calculating the number of passengers per flight, using the input schedule, type of aircraft, and load factor. The number of passengers departing during a given time interval is summed and stored. A distribution of lead times prior to departure is used to determine the number of departing passengers arriving at the airport in a given time interval. The accompanying numbers of visitors are calculated from a ratio of passengers to visitors, which varies through the day, and the appropriate number of passengers.

The count of vehicles arriving at the airport in this lead time interval is calculated and the number of those which park is also determined.

For each departure interval, the number of passengers requiring ticketing/baggage service is calculated. Times of arrival at the service are calculated using the arrival time interval and the number of intervals spent in transit from automobiles. The time spent at this function is a constant independent of the demand, so that all passengers arriving in the ticket and baggage area in one time interval will be processed and available for the waiting area in the next time interval.

Connecting passengers arrive at the airport according to a distribution based on flight departures. These passengers are transferred into the waiting area at a time equal to their arrival time on a connecting flight plus the number of time intervals required to move from the gate area to the waiting area. Upon reaching the waiting area, all passengers are entered into the total number of passengers at the waiting area and are no longer individually associated with a given flight departure.

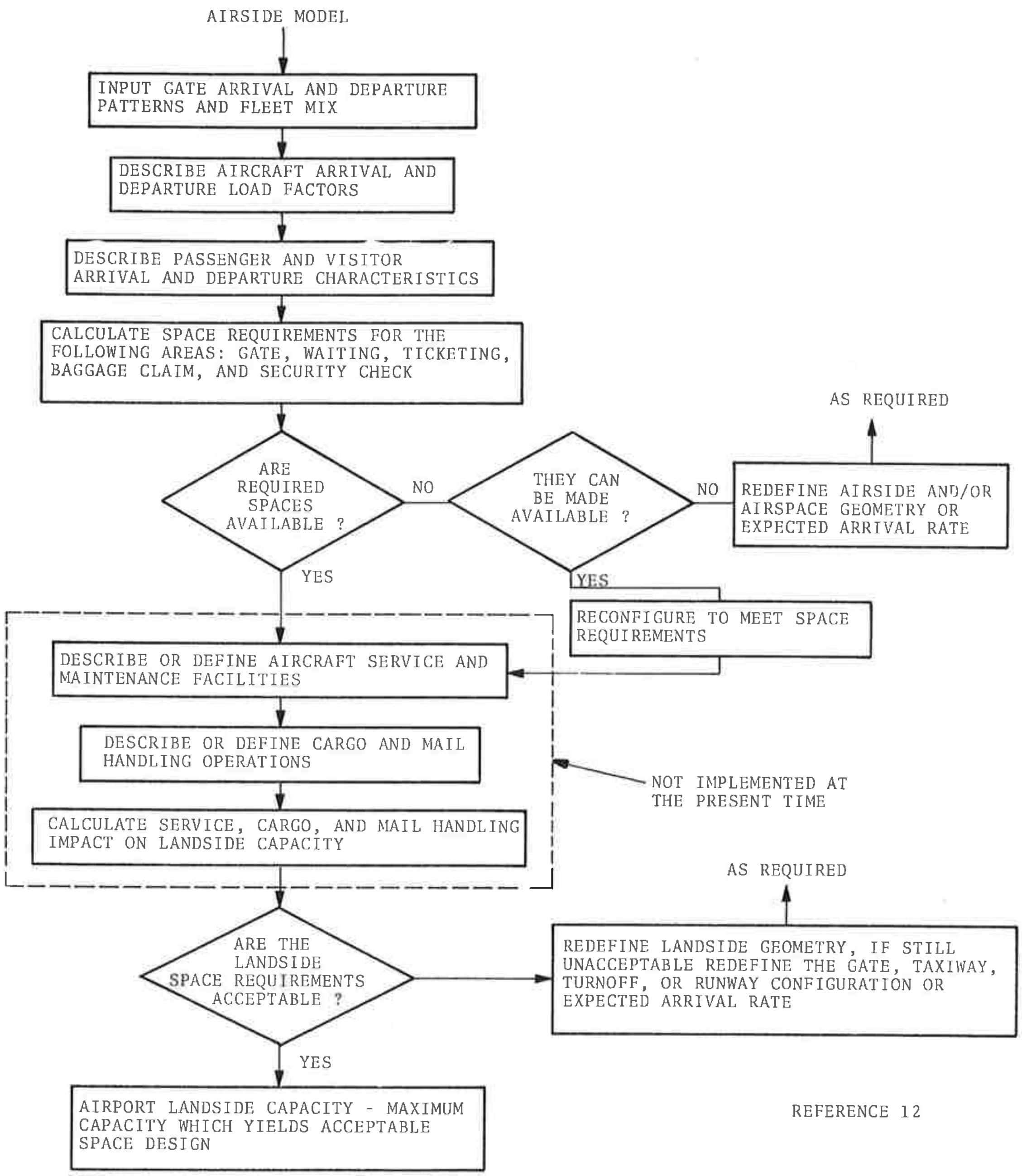


Figure 4-10 Description of Landside Model (Battelle)

The number of people passing through security is calculated based upon a distribution of lead times prior to flight time, the number of departing passengers and a percentage of their visitors being processed during this interval. The number of passengers and visitors passing through security is subtracted from the waiting area total. These passengers and visitors are then moved to the gate area and removed from the model at departure.

Numbers of arriving passengers are calculated for each daily time interval. Numbers of greeters are calculated based on arrival numbers and greeter/passenger ratios. Arrival times of greeters' cars are calculated and the cars assigned to the parking lot at proper intervals. These cars are subtracted from the totals when the appropriate arrivals are processed through the terminal.

The number of greeters is added to the waiting room total and subtracted out for passage through security or passage to the baggage claim area.

The number of vehicles at the curb is calculated and that number advanced to the deplaning roadway after one time interval.

The final computation is the conversion of peak populations of vehicles or people to space requirements. The total space is composed of the sum of the fixed space requirement per function plus the product of the space per unit and the number of units.

Table 4-12 presents the model's input data requirements and also the model's outputs. The outputs are basically the peak numbers of cars on the various roadways, curbs, or parking areas, the peak space requirements and peak populations at the various terminal functions. If so desired, the off peak values can be outputted as a function of time.

Summary

This model is intended for determining holding capacity and is not useable in its present form to determine delays or flow capacities. Statistical distributions of time spent in the airport are not available because the model does not preserve the

TABLE 4-12 INPUT/OUTPUT DATA (BATTELLE) (Sheet 1 of 4)

Passengers/Visitors	
INPUT	OUTPUT
Flight Departure/Arrival Pattern 1) Hourly 2) 10 Minute interval Aircraft Mix (by type) 1) Percent 2) Seating capacity Aircraft Load Factor 1) Percent 2) Pattern Passenger Type (Percent) 1) Originating/Terminating 2) Connecting 3) Through Enplaning Passengers Requiring Ticketing/Baggage Check-In Visitors Passing Through Security	People Population (10 Minute and Hourly) 1) Ticketing/baggage check-in 2) Security 3) Waiting areas 4) Gate check-in 5) Baggage Claim Terminal Building Space 1) Ticketing/baggage check-in 2) Security 3) Waiting areas 4) Gate check-in 5) Baggage Claim

TABLE 4-12 INPUT/OUTPUT DATA (BATTELLE) (Sheet 2 of 4)

Passengers/Visitors - Continued	
INPUT	OUTPUT
Time Distributions	
1) Enplaning Passengers/Visitors before departure	
2) At security check	
3) Visitors meeting deplaning passengers	
4) Baggage Claim waiting	
5) Connecting Passengers waiting	
Passengers Who are Accompanied by Visitors	
1) Enplaning	
2) Deplaning	
Visitors per Passenger	
Process/Transit Time Intervals Between:	
1) Arrival at airport boundary and parking or curbside	
2) Parking lot and ticketing or waiting area	
3) Curbside and ticketing or waiting area	
4) Security check and gate	

TABLE 4-12 INPUT/OUTPUT DATA (BATTELLE) (Sheet 3 of 4)

Passengers/Visitors - Continued	
INPUT	OUTPUT
5) Passenger Departures and Accompanying Visitor Departures from Parking Lot 6) Deplaning gate and baggage claim 7) Baggage Claim and curb 8) Baggage Claim and parking 9) Deplaning gate and curb 10) Deplaning gate and parking Acceptable Space Allowance for: 1) Ticket area per passenger 2) Ticket area per visitor 3) Waiting area per passenger or visitor 4) Security area per passenger or visitor 5) Gate area per passenger or visitor 6) Baggage area per passenger or visitor 7) Baggage Claim device	

TABLE 4-12 INPUT/OUTPUT DATA (BATTELLE) (Sheet 4 of 4)

Airport User Vehicles	
INPUT	OUTPUT
Parked Cars 1) No visitors 2) With visitors Time Distribution of Auto Parking Duration Passengers per Vehicle Type Acceptable Space Allowance for: 1) Parked car 2) Curbside vehicle Passengers Dropped at Curb 3) Auto with Visitor 4) Cab/Limousine 5) Bus	Vehicle Populations 1) Parking lot 2) Curbside 3) On-Airport roadways On-Airport Space 1) Auto parking lot 2) Curbside frontage

identity of passenger groups. As a population counter, it is generally useable for any airport regardless of airport configuration.

4.6 THE UNIVERSITY OF WATERLOO SIMULATION MODEL

The University of Waterloo simulation model is an accounting type designed to produce space layout and management plans for an airport passenger terminal system[13]. Space layout is the physical planning of size, shape, and relative location of spaces. Space management is operational planning involving the useage of space. Based on input data shown in Table 4-13, the model synthesizes the size and shape of major terminal components, assigns flight traffic to these components, and establishes the relative location of these components. Table 4-14 lists the outputs of the model.

TABLE 4-13 INPUT DATA FOR U. OF WATERLOO SIMULATION MODEL

Airline Schedule
Number of Classes of Aircraft
Aircraft Size
Passenger Load Sizes
Aircraft Capacity and Load Factors
Facility Data
1) Types of Facility
2) Load Schedule
3) Number of Facilities
Facility Linkage Data
Occupancy Standards Data

TABLE 4-14 OUTPUT DATA FOR UNIVERSITY OF WATERLOO SIMULATION MODEL

Set of Terminal Facility Space Plans
Set of Load Assignments for these Facility Space Plans
Set of Facility Layouts

The model is a population counter that translates the peak hour load demands imposed on the airport into raw terminal space, based on certain assumed terminal space standards. The shape of the supplied space is governed by technology factors such as size of aircraft. The location of the space is governed by the daily flight traffic flows and types of activity.

The model is composed of three major algorithms: (1) the facility sizing algorithm, (2) the load assignment algorithm, and (3) the facility layout algorithm. The facility sizing algorithm determines the amount of space that must be supplied to meet the demands. The load assignment algorithm assigns loads (flight traffic) to the facility to minimize the summation of passenger flow times distances products. The facility layout algorithm locates the facilities in relation to each other to minimize transport costs. An "optimum" airport design is iteratively achieved using the load assignment algorithm to reduce the transport costs. The output data of the model is shown in Table 4-14.

The model describes passenger activities from aircraft block time to the time the passengers enter the terminal lobby. The major part of the model assumes a multi-stage queueing process. Stochastic factors incorporated in the model include deplaning rates of passengers and baggage, and processing rates of each facility.

<u>Summary</u>

This model synthesizes airport terminal space plans based on population counting. This model does not approach the criteria assumed in this report for selecting future study methods since it does not simulate flow times. The model is experimental and has not been validated.

4.7 THE CANADIAN MINISTRY OF TRANSPORT CALGARY MODEL

The Canadian Ministry of Transport model was developed to assist in the determination of future space requirements within and around an air terminal building[14]. This is a queueing model which in some cases uses randomly distributed service times such as those at Air Canada ticket counters. At other service locations such as Western Air Lines, it uses a fixed service time. Each departing passenger is described by the number of well wishers in the group, ticketing or baggage requirements, time of arrival at the terminal, the airline to be used, the flight time and the boarding gate. Arriving passengers are characterized by the number of greeters in the group, greeter arrival times at the terminal, passenger arrival time, airline used and the deplaning gate.

Table 4-15 shows the model inputs. The simulation begins with the arrival of a group containing the departing passengers and well wishers at the curbside. The group size is determined by the distribution function which randomly assigns well wishers to each passenger. These passengers are sent to the appropriate ticket and check-in counters and services according to randomly calculated times. If the service areas are filled with passengers at that time, the newly arrived passengers remain where they are and their delay times recorded. Domestic passengers are routed through specified parts of the terminal such as the lobby, security check and finally the gate, where they are removed from the model. During this process, well wishers are separated from passengers and movements are conducted at specified times relative to the flight departure.

International and transborder passengers are routed through an international area and a security check to the international gate area where they are removed from the simulation.

Some specified percentage of each type of passenger is diverted to a mezzanine area as long as sufficient time (25-30 minutes) remains before flight time. The model determines whether or not a passenger has sufficient time to make his flight while at an intermediate location in the terminal. Should the passenger not have the necessary time, he is counted as a member of those missing that flight and is removed from the simulation.

TABLE 4-15 CANADIAN MINISTRY OF TRANSPORT CALGARY MODEL (INPUT)

Input Data
Storage Area Capacities
Flight Times
Numbers of Ticket Counters
Name of Airline
Number of Passengers per Flight
Flight Gate
Flight Destination
Ticket and Baggage Counter Capacities
Ticket and Baggage Counter Service Times
Number in Passenger Group
Ticket and Baggage Requirements

Greeters are assigned to each passenger and they arrive at the arrivals-level driveway according to a predetermined arrival schedule. The input distribution is a function of time relative to flight arrival times. The greeters proceed to the curb and then to the terminal. They proceed through various terminal areas, based on the arrival gate of the flight to be met, and enter a public waiting area where they meet their respective passengers.

Domestic arriving passengers proceed down the appropriate corridors to the public waiting areas and either meet greeters and are routed to the baggage area via a lobby, or proceed directly to there alone. A simulation of the baggage collection is performed, after which these passengers move out of the building through the curb area and are removed from the simulation.

The output data, shown in Table 4-16, consists of queue lengths at specified times, the total numbers of people arriving at a server during the previous period, the average times of delays, the numbers of passengers flowing through hold areas and the contents of the hold areas at specified times. Times associated with movements and hold area waits are fixed and independent of occupancy.

TABLE 4-16 CANADIAN MINISTRY OF TRANSPORT CALGARY MODEL (OUTPUT)

Output Data
Number of Entries During Period
Queue Total Entries
Average Time per Transaction
Storage Area Contents
Queue Maximum and Average Limits

Summary

This model is a queueing model which in some instances uses fixed service times so that some delays are deterministic, such as at several ticket and baggage counters. For security and customs, a distribution of service times is used. The model is structured to simulate the passenger routing through the Calgary airport only, although the logic used to describe any server could be applied to any airport. Distribution of passenger delays could be obtained from this model on a per-flight basis. However, the simulation is presently limited in coverage from the curbside to the gate.

5. CONCLUSIONS AND RECOMMENDATIONS

The authors have concluded, as a result of this study, that a dynamic time-oriented queueing event simulation model is the most appropriate type for studying airport landside activities and operation. The short-term objective of any future landside study program should be to develop a simulation model that can dynamically measure the impact of congestion on airport level of service using passenger delays as the principal measure of level of service.

A review of existing simulation models indicates that none fully meets the foregoing objectives. However, it appears that the computer models using the time-oriented queueing methodology can potentially be satisfactorily extended. Table 5-1 summarizes the existing computer models considered by this study. The Bechtel model and the TAMS model most closely match the study criteria but these models need to be significantly extended, incorporating logic for computing the passenger delay distributions, to meet study criteria.

Approximate computer run time and cost data were obtained from Bechtel and TAMS. The information, shown in Table 5-2, must be viewed as order of magnitude estimates since it is based on personal recollection rather than documented computer run times. Due to the incompleteness of the information, valid comparisons in run times between these two models are not possible.

In addition to the computation of airport level-of-service, airport landside simulation model validation needs careful study. None of the models reviewed has been truly validated. It is recommended that a methodology be developed for correlating simulation data with field data for this purpose so that simulation models providing a high level of confidence can be designed. An extensive data collection effort will be needed to support the application of such methodology. Such field data can also provide a common reference against which several different simulation models can be compared.

TABLE 5-1 SUMMARY OF EXISTING COMPUTER MODELS

Model Name	Language	Boundaries	Type	Input Data	Output Data	Level of Validation	Applicability
Bechtel	GPSS 5	Airport Boundary to Gate	Time-Oriented Queueing Model	• Facility Layout & Dimensions • Flight Schedule Data • Facility Service Times • Passenger Data	• Quantity of Passengers/Vehicles/Baggage Processed • Passenger Flow Times • Facility Processing & Waiting Times	Partial Validation	Applicable, but Requires Adaptation to Provide Delay Statistics
TAMS	GPSS	Airport Boundary to Gate	Time-Oriented Queuing Model	• Flight Schedule Data • Passenger Data • Facility Service Times • Arrival & Departure Distribution Data	• Quantity of Passengers/Vehicles/Baggage Processed • Passenger Flow Time • Queue Lengths • Facility Utilization Statistics	Not Validated	Applicable, but Requires Adaptation to Provide Delay Statistics
PONYA	GPSS-2	International Terminal Building (Gate to Curb Arrivals Only)	Time-Oriented Queueing Model	• Terminal Building Configuration • Arrival Rates • Service Time Distributions • Passenger Data	• Quantity of Passengers/Baggage Processed • Waiting Times • Queue Lengths	Partial Validation	Not Presently Applicable (For Arrivals Only)
M.I.T.	GPSS	Parking Garage to Gate	Time-Oriented Queueing Model	• Flight Schedule • Arrival Rate Function • Transit Speeds • Service Time Distributions • Passenger Data	• Quantities of Passengers Processed • Queue Lengths and Occupancy Distributions • Waiting Time Distribution	Not Validated	Not Presently Applicable (Configured for Metroport Concept)
Battelle	Fortran	Airport Boundary to Gate	Accounting	• Flight Schedule • Arrival Percentages • Transit Times • Service Times	• Population Distributions • Landside Space Requirements	Not Validated	Not Applicable (Provides Only Occupancy Data)
University of Waterloo	GPSS	Terminal Building Only	Accounting	• Flight Schedule • Passenger Load Factors • Facility Data • Occupancy Standards	• Set of Terminal Facility Space Plans • Set of Load Assignments • Set of Facility Layouts	Not Validated	Not Applicable (Produces Population Count and Terminal Design Data)
Calgary	GPSS	Curbside to Gate	Time-Oriented Queueing Model	• Number of Facilities • Storage Area Capacities • Flight Schedule Data • Passenger Data • Service Time Distributions	• Quantities of Passengers Processed • Average Time/Transaction • Wait Area Occupancy • Queue Contents	Not Validated	Not Presently Applicable (Extends Only From Curb to Gate)

TABLE 5-2 RUN TIME COST DATA FOR BECHTEL AND TAMS MODELS

Bechtel Model:	6 minutes CPU/6 hour simulation time at Denver Airport; 4000 passenger/hour; 8-10 million passengers/year airport. $150-200/run on IBM 300/65
TAMS Model:	1 minutes CPU/4 hour simulation time at Maiquetia Airport for Terminal Model only; $100/run on IBM 300/135

The use of a validated simulation model in the planning of airports has many potential applications in addition to those listed in Section 1.0. Some of the other studies and investigations that an airport landside simulation model can carry out more quickly, effectively and economically than other methods include:

Design evaluation - the evaluation of the preliminary design of an airport or proposed change in airport design.

Hypothesis testing - experiments which would be difficult or impossible to carry out in a physical system (effects of changes in operation policy or design).

Inter-relationship studies - experiments to establish the relationships between facilities.

Failure testing - studies of the impact of facility failures on airport operation.

The results of the computer simulations can also be used to evaluate the impact of such factors as changed flight schedules, unscheduled flights, improvements in facility design and layout, changes in routing strategy, facility/sub-facility malfunctions and aircraft delays on airport congestion and passenger delays. In particular, when serious congestion and passenger delays exist, computer simulation models can provide information about whether changes in flight schedule, improvements in facility design and layout or changes in routing can reduce or eliminate congestion and delay problems.

APPENDIX A
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APPENDIX B

GLOSSARY

Airport	A transportation system that is an interface between the ground transportation system and the air transportation system.
Dynamic System (Model)	A system (model) with interactions that change with time.
Analytical Model	A model representing a physical system expressed in deterministic mathematical equations.
Event	An occurrance or a change in a system (model) at a point in time.
Event Simulation	Computation of changes in the state of a system through random number generation
Landside	That part of an airport's ground facilities and activities between the gates and the airport boundaries.
Model	A mathematical representation of a physical system.
Simulation	The study of the dynamic behavior of a system using a model.
Statistic	A measure computed from sampled data derived from the system (model).
System	An interactive collection of components.
Time Oriented Model	A mathematical model that reproduces a system by the solution of dynamic equations expressing the relationship among segments of the system.
Stochastic	Describes a variable of the system (model) that exhibits random behavior.
Measure	A quantity used to describe a characteristic of the system (model).
Probability	A measure of the likelihood of the occurerance of a random nature event.

Validation	A test to determine the accuracy of the simulation model in representing the physical system to a specified level of confidence.
Gate	The terminal door that passengers use to enplane or deplane.
Facility/Sub-Facility	An airport sub-system performing some service.
Visitor	A person meeting or accompanying a passenger at the airport.
Seat Flow	The total aircraft seats available per unit time at the airport.
Inter-Arrival Times	The difference between arrival times of successive passengers or vehicles.