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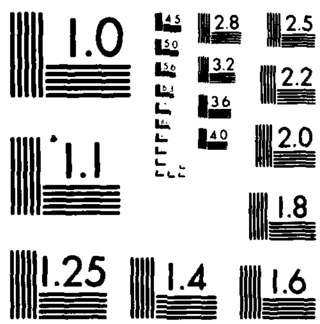

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Airport Landside
Volume I: Planning Guide

L. McCabe
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Transportation Systems Center
Cambridge MA 02142

June 1982
Final Report

U.S. Department of Transportation
Federal Aviation Administration

Office of Systems Engineering and Management
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16. Abstract

This volume describes a methodology for performing airport landside planning by applying the Airport Landside Simulation Model (ALSIM) developed by TSC. For this analysis, the airport landside is defined as extending from the airport boundary to the aircraft gate. The model routes simulated enplaning and deplaning passenger groups through a series of essential processing facilities. At the simulated facilities, queueing and service processes are modeled. Flow, queueing time, queue length, and occupancy statistics are produced.

This guide describes how the model output may be applied to a landside capacity analysis. It also discusses using the model for management of daily operations and airport design. A description of input data necessary for model operation is presented with examples using data from Miami, Denver, and La Guardia airports.

Other volumes of the Airport Landside report are: Volume II: the Airport Landside Simulation Model (ALSIM) Description and Users Guide; Volume III: ALSIM Calibration and Validation; Volume IV: Appendix A ALSIM AUXILIARY and MAIN Programs; and, Volume V: Appendix B ALSIM Subroutines.

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PREFACE

The Airport Landside Simulation Model (ALSIM) provides a method of examining passenger handling operations as a system. New approaches for solving existing problems may be examined by using this model, or congestion arising from projected demands may also be evaluated.

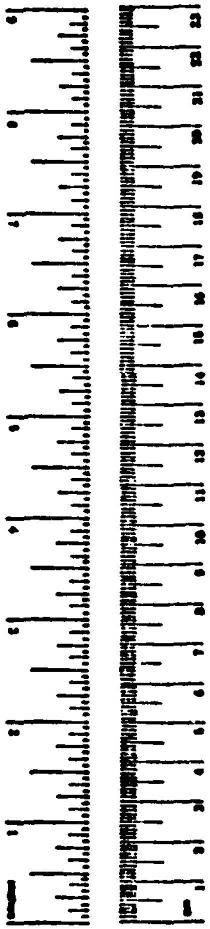
This model has been described previously in a paper delivered at the Air Transportation Meeting in Boston, May 1-4, 1978. Report number 780516 of the Society of Automotive Engineers, Technical Paper Series, contains this description. Detailed documentation is contained in Volumes II, IV and V of this report. The model was tested for validity using data obtained at Miami, Denver and La Guardia airports. A description of data collection procedures used at these airports is contained in report FAA-EM-80-2. Validation results are contained in Volume III of this report.

The authors wish to express their appreciation to Professor Amodeo Odoni, Massachusetts Institute of Technology, for technical assistance. The contribution of Input-Output Computer Services, Incorporated in preparation of this volume is also appreciated.

METRIC CONVERSION FACTORS

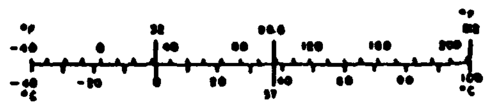
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY

This is an introductory document intended to familiarize planners and designers of airport terminals with a computer model capable of analyzing flow and congestion phenomena on the airport landside. The Airport Landside Simulation Model (ALSIM) is described and a set of typical landside planning applications are presented. These include (1) management of daily operations, (2) airport design and master planning, (3) landside capacity analysis, and (4) cost/benefit analysis of landside investments.

Model outputs consisting of values of flow, queueing time, queue length and occupancy at simulated landside processing facilities are parameters used in these applications. This document indicates how the model outputs may be applied.

Input data for ALSIM is divided into four categories: flight schedules, passenger characteristics, airport geometry, and facility characteristics. A discussion of sampling requirements and costs for obtaining data is presented. Representative data obtained from Miami International, Denver Stapleton, and LaGuardia Airports is exhibited. Similarities and differences among the airport data are discussed.

An appendix relating airside to landside capacity is contained in this document. Applications to ALSIM and a suggested methodology for determining landside capacity based upon average landside delay at a given passenger flow is provided.

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1. INTRODUCTION

This report describes how a fast-time simulation program, the Airport Landside Simulation Model (ALSIM), can be used as an aid in airport planning, specifically in airport design and master planning, in landside capacity analysis and in cost/benefit analysis of airport investments. ALSIM, which is designed to be applicable to many existing or hypothetical landside configurations, was originally obtained by the U.S. Department of Transportation from the Bechtel Corporation and was subsequently enhanced and modified by the Transportation Systems Center (TSC). It is now available for general use by airport planners. The use of simulation in master planning, landside capacity analysis and cost/benefit analysis is recommended for large airports by the FAA (Airport Master Plans, Chapter 3, Advisory Circular AC 150/5070-6).

2. DEFINITION OF AIRPORT LANDSIDE

For the purposes of this report, the airport landside is defined as the area bounded by the point at which the passenger enters or leaves the airport proper ,whether by one of the transit modes, private automobile, or other means , and by the point on the apron at which the passenger actually enters , or leaves , the aircraft. The landside can be viewed as a combination of service or processing facilities such as, ticket and baggage check-in counters, security checking, immigration clearance, customs clearance, baggage claim devices and parking facility exits. The landside also includes access/egress facilities and areas such as roadways, curbside, parking lots, waiting lounges, corridors and walkways.

While recognizing the presence and the importance of other landside aviation-related activities, namely, airline maintenance hangars, cargo and airmail facilities, general aviation buildings and crash-fire-rescue facilities this report concentrates exclusively on activities related to the service of air travelers using the commercial airline system.

3. BRIEF DESCRIPTION OF THE AIRPORT LANDSIDE SIMULATION MODEL (ALSIM) AND ITS OUTPUTS

ALSIM is a computer simulation program written in GPSS-V which models the flow of people and vehicles through the airport landside, the region between the aircraft and the airport boundary. The model represents essential landside processing facilities and simulates the arrival, queueing and service processes simultaneously occuring at each location. Movement times between facilities are also represented. Enplaning and deplaning passenger groups, airport visitors and vehicles are represented by GPSS-V transactions that are routed through program modules representing landside processing facilities. The location of each processor, the number of servers available and applicable service time distributions are provided to the model as input data. A flight schedule representing the demand to be placed upon the landside is input and provides a mechanism for generating the model transactions by specifying the number of arriving, departing or transfer passengers on each flight. Passenger characteristic input data is used to assign attributes to each transaction. These attributes will determine the passenger group size, affect the routing through the landside and specify simulation times of arrival at the airport for originating passengers and greeters subsequently meeting terminating passengers.

The model is operated for a predetermined simulation time period. Continual arrivals of simulated aircraft and ground transportation vehicles introduce transactions into the model which subsequently are processed through the simulated facilities and depart the landside via aircraft or ground modes. During the simulated time period, the model is capable of producing flow, queue length and occupancy data. Flow data consists of the numbers of persons or vehicles discharged by a facility through a designated location over a specified time interval. For ALSIM the counts are accumulated every five minutes. Queue length data, consisting of the instantaneous count of persons or vehicles queueing at simulated facilities, is produced at each five minute mark. Occupancy counts, the numbers of persons present at input landside points, are also output at each five minute time point.

At the conclusion of each simulated hour, a table is produced consisting of a total queueing time distribution for transactions terminated during the hour. This table provides the average queueing time experienced by these terminated transactions during landside processing and the percentage of transactions with queueing times within each 100 second interval. These averages and tabular values may be used for subsequent capacity analysis.

When the simulation period ends, extensive summary data is output for each simulated facility. Cumulative flow through each processor is provided and congestion parameters expressed as average queue time and average queue size are produced. The utilization of the facility, expressed as the average number of servers busy is also provided by the model.

Table 3-1 provides a summary of the model outputs at essential landside facilities. The flow, occupancy and queue size data is available as time series output through the simulation time period. Cumulative flow, average queue size and average waiting time are produced as cumulative statistics at the completion of the run. Average utilization, expressed as the average number of servers busy during the simulation period is produced by ALSIM. Details and examples of output data are provided in Volume II of this report.

Responsibility for ALSIM dissemination has been assigned by the U.S. Department of Transportation to the following organization:

FAA Technical Center
Airports Technology Division
Atlantic City Airport, New Jersey 08405

TABLE 3-1. SUMMARY OF MODEL OUTPUTS

	FLOW	AVERAGE QUEUE TIME	OCCUPANCY	AVERAGE UTILIZATION	QUEUE SIZE
INBOUND ROADWAY	X				
ENPLANING CURB	X	X	X	X	X
EXPRESS CHECK-IN	X	X	X	X	X
FULL SERVICE COUNTER	X	X	X	X	X
SECURITY	X	X		X	X
GATE COUNTER	X	X	X	X	X
BAG CLAIM		X	X		
RENTAL CAR COUNTER	X	X	X	X	X
DEPLANING CURB	X	X	X	X	X
PARKING FACILITY			X		
PARKING FACILITY EXIT	X	X		X	X
OUTBOUND ROADWAY	X				
CUSTOMS	X	X	X	X	X
IMMIGRATION	X	X	X	X	X

4. FEATURES AND LIMITATIONS OF AIRPORT LANDSIDE SIMULATION MODEL (ALSIM)

ALSIM was developed after a careful review and consideration of other existing landside simulation packages. It includes most of the attractive features of these packages while eliminating some of their disadvantages. The following are some of ALSIM's features:

a. Provides simulation of all significant passenger-processing landside facilities.

b. Is highly flexible and ideally suited for exploring the effects of changes in landside configurations and designs.

c. Can be used to simulate individual facilities, groups of facilities or the entire landside complex at any desirable level of detail and for any desired time interval.

d. Automatically collects and tabulates virtually all statistical information that could be of interest to the designer or planner.

e. Is relatively inexpensive to use.

f. Has been partially calibrated and validated at three large hub airports in the United States.

On the other hand, it should be emphasized that ALSIM should be used to supplement the designer's or planner's judgment, experience and imagination and not as a substitute for these qualities. For instance, while ALSIM includes among its outputs some of the most important quantifiable descriptors of the landside level of service perceived by airport patrons, for example,

- The length of walking distances experienced by landside users,
- The duration of total processing times at the various landside service facilities,

- The amount of time spent waiting in a queue to receive service at the landside service facilities,
- The amount of congestion experienced in terms of people located at a specified occupant landside point.

It does not deal with other important quantitative or qualitative descriptors, such as,

- The reliability of the service provided at various facilities,
- The effectiveness of signing or sense of directivity on landside,
- The quality of safety-related procedures,
- The demeanor and courtesy of airport employees,
- The esthetic appeal of landside buildings.

5. APPLICATIONS OF AIRPORT LANDSIDE SIMULATION MODEL (ALSIM)

The following describe typical applications of ALSIM in landside planning:

a. Management of Daily Operations: In managing the operations of landside facilities, airport operators must typically face problems such as:

- anticipate and plan for surges in demand (caused, e.g., by the scheduled arrival or departure of several wide-body aircraft within a short period of time);
- schedule and allocate personnel so as to offer the best service possible with the available manpower;
- anticipate the effects on landside operations of administrative decisions such as the scheduling and gate assignment of charter flights or allowing well-wishers (and greeters) to accompany travelers to (from) departure (arrival) gates;
- forecast the effects of new, capacity-increasing equipment at the various facilities.

These and similar problems can be solved with the aid of ALSIM through an essentially "trial-and-error" approach. The anticipated schedule of flights can be simulated and the effects of management actions, administrative decisions, new equipment, as the case might be, can be observed. Various alternatives can be tried out by the airport operator during successive runs of the computer program until the level of performance is deemed satisfactory.

b. Airport Design and Master Planning: Typically airport master plans take into account short, intermediate and long-range demand forecasts (approximately of 5, 10, and 20 years, respectively). The aim is to select that design and phased program of development which, in the opinion of the planning team, will best satisfy the anticipated needs.

ALSIM is a particularly effective tool for testing any given design and airport development program with respect to such important aspects of service as congestion, processing times, walking distances and crowding. Moreover, the simulation and observation of the performance of alternative designs is likely to suggest variations which will improve the level of service perceived by airport patrons, at specific points or in entire sections of the airport.

It is expected that in this type of use, planners will provide alternative basic designs (e.g., a linear, a finger-pier or a satellite terminal configuration) and will subsequently employ ALSIM and landside capacity and cost/benefit analysis as an aid to determine the optimal design for each basic alternative. Necessary checks on designs include ascertaining that the level of congestion at each individual point and for the entire landside does not exceed the standards set in the landside/capacity analysis: that the level of congestion at the various service points is approximately the same (no serious "bottlenecks"); and that no individual category of passengers or visitors is penalized excessively by a particular design. All these checks can be performed through ALSIM. In general, the model is ideally suited for this type of use because of the ease with which changes in landside configuration can be programmed and simulated by ALSIM.

c. Landside Capacity Analysis: Landside capacity analysis is an essential step in master planning and in determining the need for and timing of expansion of facilities. Forecasting of demand and determination of airport capacity are the two constituent parts of a capacity analysis. Landside airport capacity can be determined through the use of ALSIM.

The capacity of a landside facility (or of a sequence of facilities) is defined as the maximum number of facility patrons who can be processed per unit of time without the time spent waiting exceeding some pre-specified threshold values. This definition of capacity is consistent with that most often used for airside facilities. Average queueing time is the most often used indicator of congestion.

To estimate the capacity of a landside facility using ALSIM, the facility is simulated for several different values of the hourly flow of patrons through it. This yields a curve of the type shown in Figure 5-1. For any specified threshold value of delay, one can then "read" from the curve the capacity of the facility (facilities). To date, no organization, such as the FAA or ICAO, has specified threshold values for landside queueing time, and, consequently, no generally accepted national or international standards exist. Airport operators and planners should, therefore, exercise their own judgement in specifying such threshold values. It is suggested that threshold values for landside should be such that, when the airport under consideration is operating at or near its capacity, the queueing times experienced on landside will be of comparable magnitude to those experienced on airside.

Appendices C and D of this volume provide further details on the use of ALSIM to estimate landside capacity.

d. Cost/Benefit Analysis of Landside Investments: When improvements proposed in a landside area or facility will increase the capacity of that area or facility to handle air travellers, then the waiting times of these travellers in this area will be reduced. These reductions in waiting times will also reduce the monetary costs of travel for these passengers. The economic worth of the time savings can be compared with the costs of landside improvements and cost-benefit relationships can be established.

Once again, ALSIM is well-suited for determining the time savings due to reductions in queueing times that accompany increases in landside processing capacity. For this purpose, the landside facility or area in question can be simulated "before" and "after" the proposed improvement. The difference in the total queueing time estimated by the "before" and "after" simulations represents the time savings to travellers. The total annual

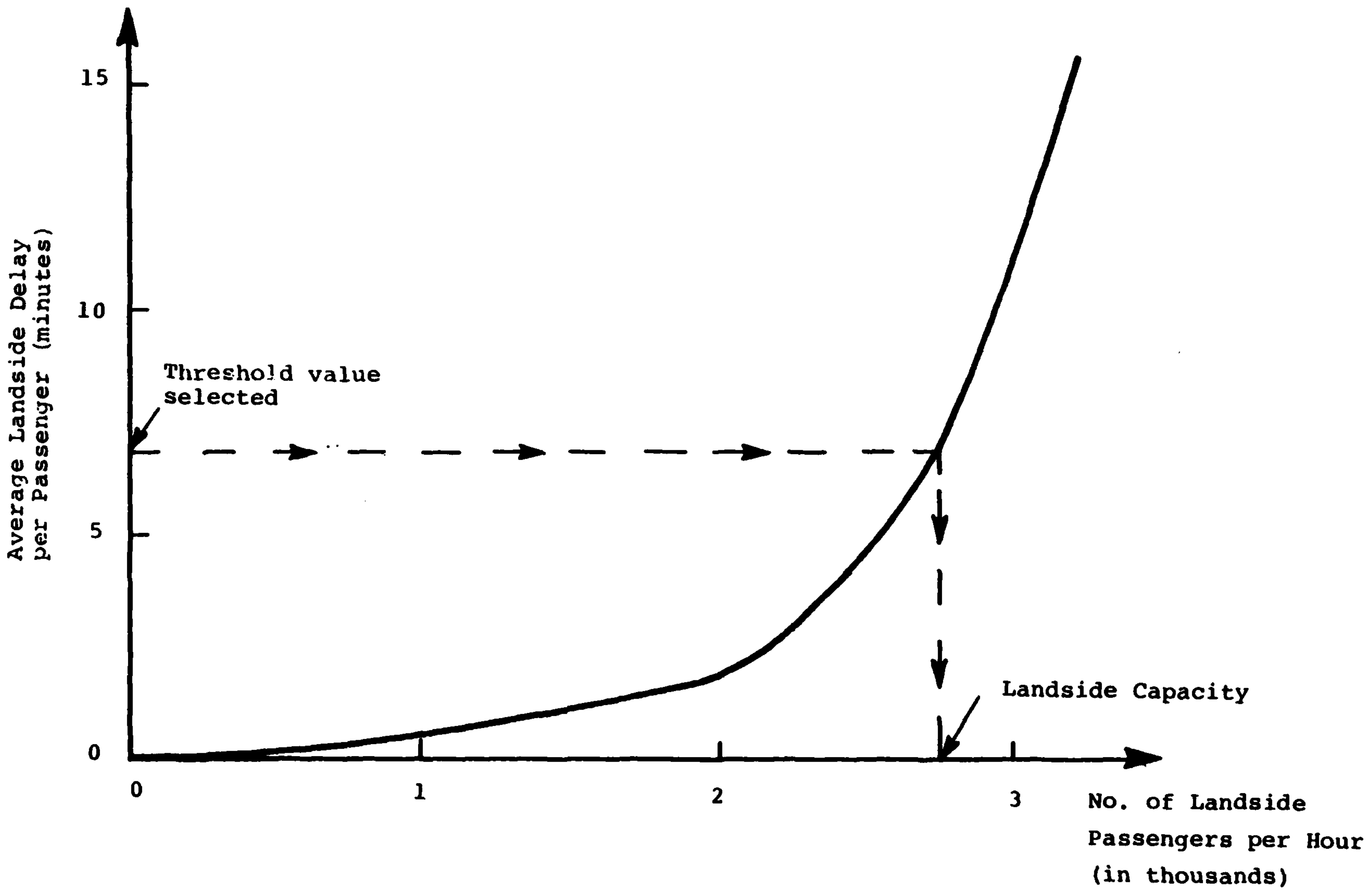

FIGURE 5-1. AVERAGE DELAY VS. PASSENGER FLOW ON AIRPORT LANDSIDE

time savings (passenger-hours per year) must then be multiplied by the average monetary value of time for air travellers to estimate the monetary benefits due to the improvement.

Next, the cost of the improvement is estimated and spread over a period of amortization. The present worth of the costs and benefits over the period of amortization ("lifetime") are then compared and the net present value of the proposed improvement is obtained. This procedure is described in more detail in Appendix D of this volume.

Cost/benefit analysis should be applied in justifying and selecting the time for the addition of new equipment on landside, the construction of new facilities (or the expansion of existing ones) and major hirings of additional airport personnel. Similarly, in allocating the annual capital budget at each airport, a cost/benefit analysis should be used for comparing the merits of the various alternatives to which the available funds can be allocated and for selecting the most cost-beneficial ones. Finally, a cost/benefit analysis could be used in support of applications by local airport authorities for Federal ADAP funds. Cost/benefit comparisons need not be limited to landside improvements only; they can be performed, as well, in the context of allocating funds between airside and landside investments, as described in AC 150/5070-6 (See Section 3, of the Advisory Circular).

e. Federal Fund Allocation and Assistance to Local Authorities: The FAA is charged by law with determining the allocation of ADAP funds among local Airport Authorities. It is also obligated to provide assistance and guidance to local planning bodies with regard to operations management, expansion planning and resource allocation at local airports. In discharging these responsibilities, FAA personnel can make use of ALSIM in the many ways outlined in this section. ALSIM can be particularly valuable, in this context, if used to perform comparisons of the costs and benefits associated with improvements at different airports, thus obtaining an approximate ranking of the merits of fund requests from local authorities.

6. INPUT PREPARATION FOR AIRPORT LANDSIDE SIMULATION MODEL (ALSIM)

This section discusses some of the considerations that face the user with regard to the tasks of obtaining input data for the operation of ALSIM.

Table 6-1 indicates that ALSIM input requirements can be divided into four general categories: flight schedule, passenger characteristics, airport geometry, and facility characteristics.

Flight schedules and related information such as aircraft types, terminal gates, approximate total number of passengers, and number of transfer passengers on each flight can be obtained relatively easily from the Official Airline Guide and through direct contact with the airlines serving each airport. Similarly, inputs related to airport geometry can be derived from a set of airport layout plans similar to that shown in Figure 6-1. The position of enplaning curbsides, check-in facilities and security stations are obtainable from this layout plan. Drawings are generally available for all landside facilities.

By contrast, inputs on passenger characteristics and on facility characteristics will often necessitate a data gathering effort on the part of the ALSIM user. The collection and tabulation of airport-specific data necessary for running ALSIM are usually the most time consuming and costly task in using the simulation model. The size of such an effort will depend on how much of the necessary information is already on hand through earlier airport surveys and on the degree of detail and accuracy to which the user wishes to simulate the airport in question. Many airports have, over the years, accumulated a wealth of information that can be used to prepare ALSIM inputs, especially with regard to passenger characteristics. Similarly, some processing rates and service capacities of mechanical equipment can be obtained from manufacturers' specifications. If a data collection effort is undertaken, the techniques that can be

TABLE 6-1. LANDSIDE SIMULATION MODEL INPUTS

1. <u>Flight Schedule</u> Flight Number Airline Arrival/Departure Time Aircraft Type Domestic/International/Commuter Transferring Passengers Bag Claim Facility Identification Number
2. <u>Passenger Characteristics</u> Percent Preticketed Percent Using Express Check-in Passenger Routings on Landside Ground Transportation Modal Choice Passenger Group Size Well-Wishers Per Group Greeters Per Group Originating Passenger Times of Arrival Distribution Prior to Flight Arrival Distribution of Greeters Arrival Distribution of Vehicles Meeting Passengers Number of Bags Distribution Car Rental Agency Selection Distribution Percent of Well-Wishers or Greeters Proceeding to Gate Percent of Greeters Proceeding inside Terminal
3. <u>Airport Geometry</u> Point Number XY Coordinate of Point Facility Type at Point Facility Number within Type
4. <u>Facility Characteristics</u> Service Time Distributions Car/Taxi Loading and Unloading Times Number of Servers or Size of Facility Baggage Transport Time to Claim Area

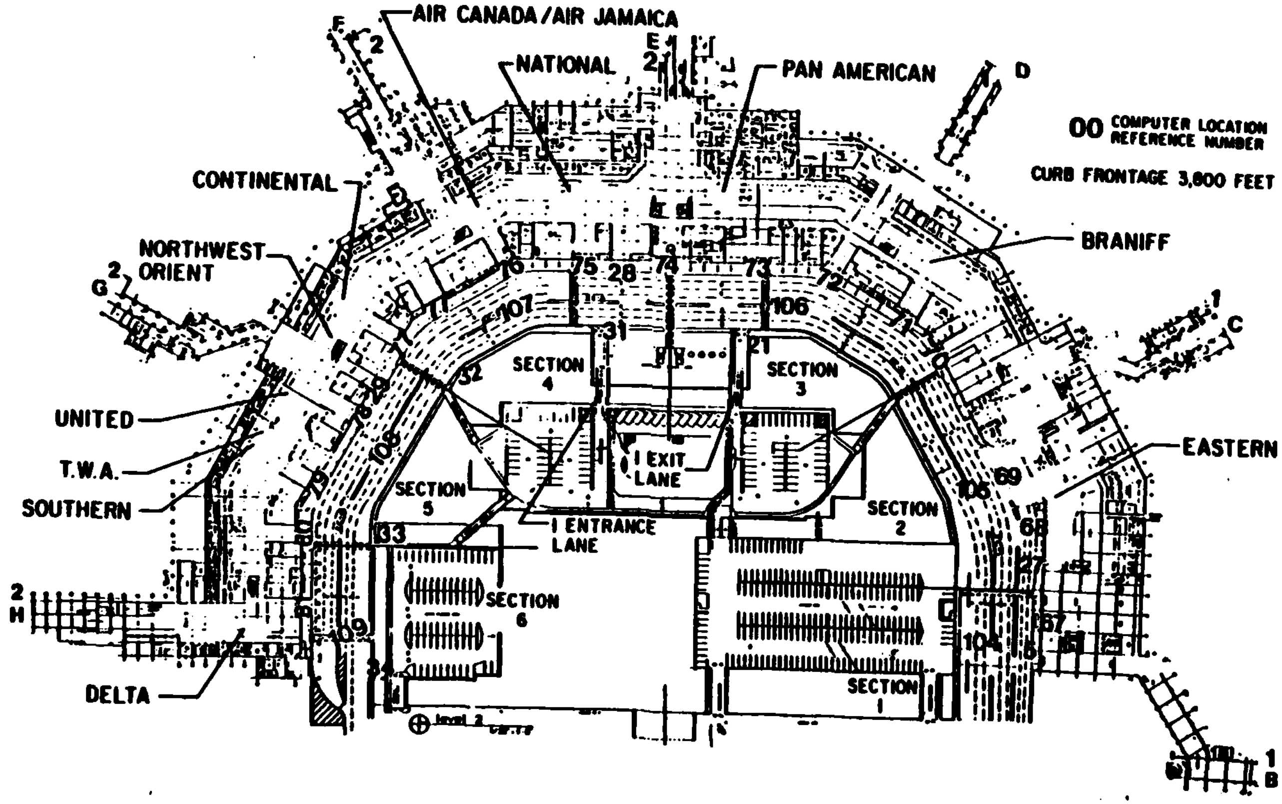

FIGURE 6-1. MIAMI TERMINAL LAYOUT

employed, depending on the nature of the desired data, include: personal interviews with airport users and employees; self-administered questionnaires collected by survey personnel; self-administered questionnaires to be mailed back by the responder; and direct traffic counts and observation of airport operations. Generally, a combination of some or all of these techniques will be used.

Costs can range from as high as $5 per usable sample for personal interviews to as low as a few cents per sample in some cases where direct observation is used. These amounts include both variable and fixed costs. Fixed costs covering preparation, planning and administration of the survey often comprise a sizeable portion of total expenditures as indicated in Figure 6-2.

The costs of data collection also vary with the degree of accuracy desired. Generally the rule is one of diminishing returns to the required number of samples. That is, as the error from the "true" value (confidence interval) to be tolerated (e.g., 10 percent, 5 percent, etc.) decreases, the number of required samples increases disproportionately. Similarly, the number of required samples increases disproportionately with increases in the confidence level desired. These relationships are depicted for a typical case in Figure 6-3. In absolute terms, the number of samples necessary to achieve typical confidence intervals and confidence levels (e.g., 10 percent confidence interval at the 95 percent confidence level) can be determined approximately through the use of simple statistical formulae. One such formula is discussed in Appendix B.

Overall, a typical large-scale, data collection effort at a major airport, aimed at gathering all the data necessary to run ALSIM may cost as much as $40,000-$50,000 (in 1979 prices). Such an effort could be conducted directly by the airport's operator or, through a contract, by a consulting firm specializing in data gathering at transportation facilities. However, a full scale effort of this type will usually not be necessary: by drawing from existing surveys and from experience and through judicious

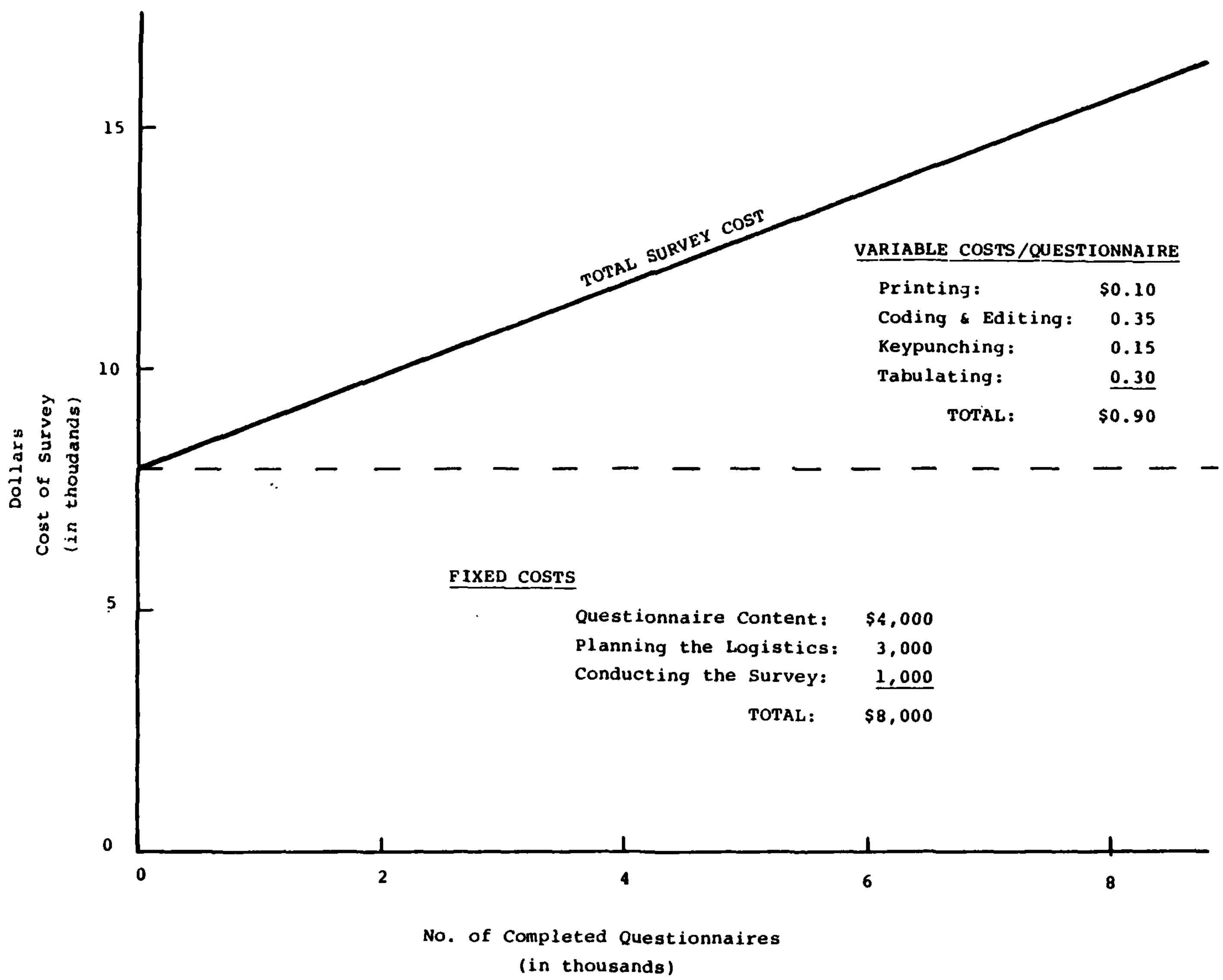

FIGURE 6-2. COST OF TYPICAL INFLIGHT SURVEY

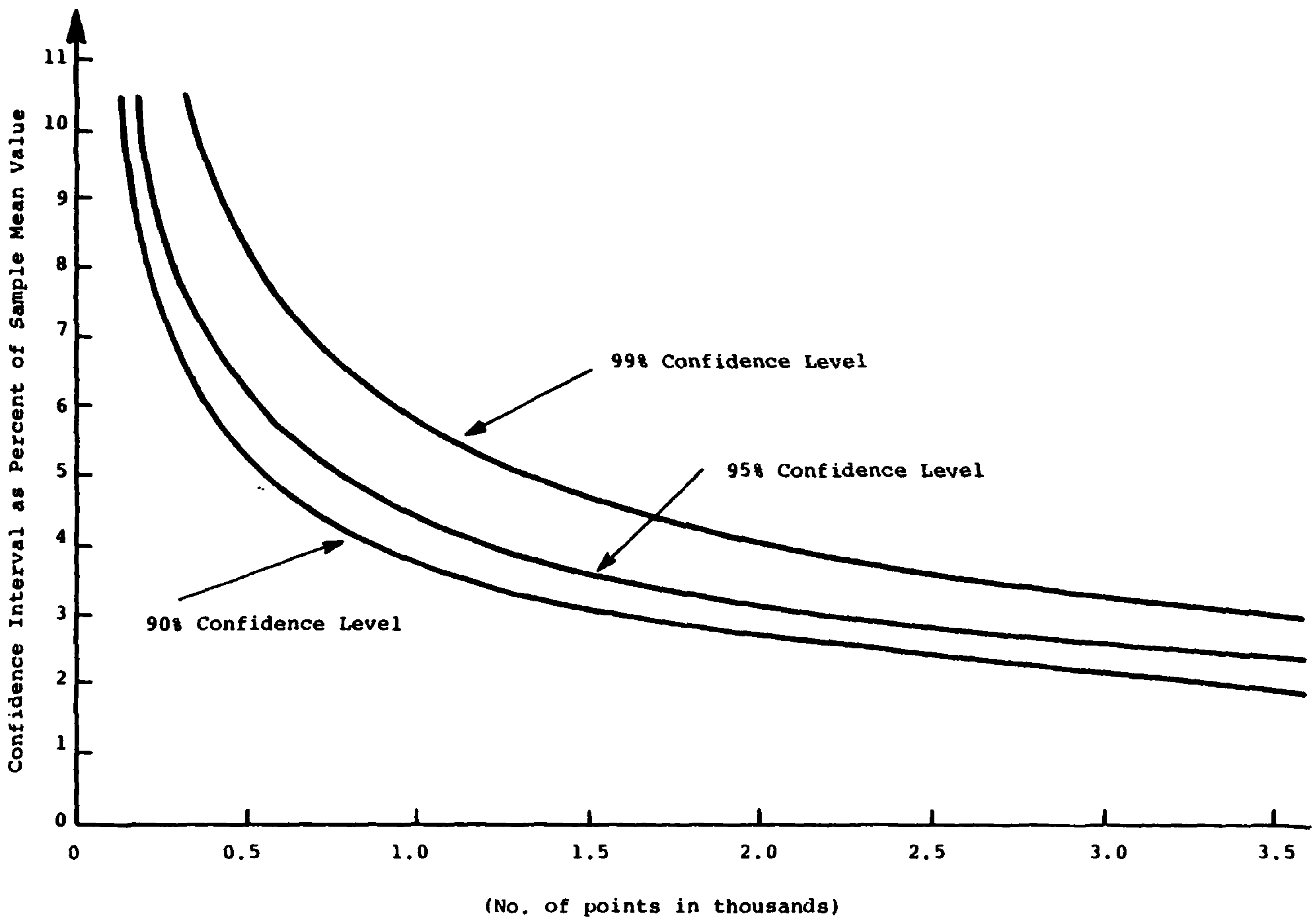

FIGURE 6-3. TYPICAL CURVES FOR NUMBER OF SAMPLE POINTS REQUIRED VS. CONFIDENCE INTERVAL AND CONFIDENCE LEVEL

use of data from other similar airports, ALSIM users will often find that data collection can be limited to only a few data items. The costs of such data collections are likely to be much smaller than those mentioned earlier.

In the process of calibrating and validating ALSIM, the U.S. Department of Transportation conducted extensive surveys and prepared complete sets of ALSIM inputs for New York's La Guardia Airport, Denver's Stapleton International, and Miami's International Airport. The data for these three airports have been tabulated and are available to ALSIM users.* They can be very useful as reference points for "guesstimates" on the values of corresponding inputs for airports that have similarities with one or more of these three. The information collected for many important data items in the categories of "passenger characteristics" and "facility characteristics," are summarized in Tables 6-2 and 6-3. The accompanying comments provide additional information for the ALSIM users. Several data items are strongly affected by local conditions and circumstances. For instance, processing times at security check points depend to a large extent on the sensitivity setting selected by airport personnel for the metal-detection equipment. A "high" setting will make it necessary for many passengers to pass through the equipment more than once, thus resulting in longer processing times. ALSIM users should carefully consider data items which Tables 6-2 and 6-3 indicate as exhibiting wide variability.

In using Tables 6-2 and 6-3 the ALSIM user must identify which (one or more) of the three airports listed is likely to be similar, with respect to passenger characteristics and to facility processing characteristics, to the airport under study. Useful criteria to consider in identifying "similarities" include:

*See: Collection of Calibration and Validation Data for an Airport Landside Dynamic Simulation Model, Wilbur Smith and Associates, prepared for the U.S. Department of Transportation/Transportation Systems Center, April 1980 (FAA-EM-80-2).

- the type of mechanical equipments in use,
- the extent of international vs. domestic travel,
- the extent of long-term vs. single-day commuter travel,
- the proportion of transfer passengers,
- the accessibility of the airport by private automobile,
- the extent to which airlines share terminal facilities.

TABLE 6-2. PASSENGER CHARACTERISTICS

DATA ITEM	MIAMI INT'L	DENVER STAPLETON	NEW YORK LA GUARDIA	COMMENTS
1. Ground Transportation Modal Choice				La Guardia airport has large number of business travelers who generally avoid use of private automobile. Driving to and parking at La Guardia are also relatively difficult.
a. Enplaning Passengers				
Private Auto	41.7%	55.8%	25.0%	
Car Rental Bus	10.7	13.6	9.3	
Taxi	21.6	13.5	45.8	
Airport Limousine	10.1	4.9	12.5	
Bus	15.4	3.3	5.2	
Other	0.5	8.9	2.2	
	100 %	100 %	100 %	
Deplaning Passengers				
b. Private Auto	47.1%	69.6%	30.7%	
Car Rental Bus	20.4	7.9	4.2	
Taxi	17.6	9.7	35.1	
Airport Limousine	9.6	4.8	20.1	
Bus	5.3	4.7	5.3	
Other	-	3.3	4.6	
	100 %	100 %	100 %	
2. Percent of Preticketed Passengers	69%	58%	62%	Percentages vary by airline; ranges are: Miami 50-91%, Denver 35-80%, La Guardia 50-75%
3. Percent of Passengers Using Express Check-in Counters	41%	27%	30%	Percentages vary by airline; ranges are: Miami 10-70%, Denver 4-50%, La Guardia 15-35%
4. Percent of Passengers Using Curbside Check-in Counters	30%	23%	20%	Percentages vary by airline; ranges are: Miami 12-67%, Denver 4-38%, La Guardia 15-25%
5. Percent of Preticketed Passengers Going Directly To Departure Gate	26%	29%	32%	Percentages vary by airline; ranges are; Miami 10-52%, Denver 5-50%, La Guardia 20-50%

TABLE 6-2. PASSENGER CHARACTERISTICS (Cont.)

DATA ITEM	MIAMI INT'L	DENVER STAPLETON	NEW YORK LA GUARDIA	COMMENTS
6. Average Number of Air Passengers per Enplaning Group (excluding well-wishers/ greeters)	2.2 pax/ group	2.16 pax/ group	2.51 pax/ group	Remarkable similarity in average group size, although there are differences in size distribution (see item 7 below).
7. Distribution of Air Passenger Group Size (excluding well-wishers/greeters				About 70-75% of all passenger groups consist of 1 or 2 travellers
1 passenger/ group	38.9%	23.7%	32.3%	
2	34.4	49.4	38.4	
3	11.5	18.7	20.0	
4	8.1	5.5	6.1	
5	3.4	2.2	1.8	
6-10	3.7	0.5	0.8	
10	-	-	0.6	
8. Distribution of Baggage per Air Passenger Group				First entry in each item refers to number of bags per passenger group which are checked in; second entry to number of carry-on bags per passenger group. Large number of business travellers at La Guardia is reflected in 36.6% with no bags to check in.
0 bags/passenger group	8.3%/ 18.9%	19.6%/ 27.2%	36.6% 26.8%	
1	11.8/ 43.3	31.6/ 48.2	26.0/ 47.0	
2	30.1/ 26.1	27.2/ 19.2	20.3/ 17.9	
3	21.2/ 6.2	13.0/ 3.8	8.6/ 4.6	
4	12.5/ 8.2	4.4/ 1.4	4.4/ 2.4	
5	5.3/1.5	1.7/0.2	1.4/0.4	
6-10	9.2/0.8	2.4/-	1.9/0.3	
>10	1.6/-	0.1/-	0.8/0.6	
	100%/ 100%	100%/ 100%	100%/ 100%	
9. Average Number of Well-Wishers per Enplaning Passenger Group	0.41 persons per enplaning group	0.43 persons per enplanning group	0.15 persons per enplaning group	Average number of greeters is about twice the number of well-wishers. Remarkable similarity between Miami and Denver where number of well-wishers/greeters is about twice that at La Guardia.
Average Number of Greeters per Deplaning Passenger Group	0.79 persons per deplaning group	0.80 persons per deplaning group	0.37 persons per deplaning group	

TABLE 6-2. PASSENGER CHARACTERISTICS (Cont.)

DATA ITEM	MIAMI INT'L	DENVER STAPLETON	NEW YORK LA GUARDIA	COMMENTS
10. Distribution of Number of Well-Wishers/Greeters by Air Passenger Group				First entry refers to number of well wishers per enplaning group, second entry to number of greeters per deplaning group. As suggested by item 9 above, greeters in all cases outnumber well-wishers.
0 persons/passenger group	74.1%/ 57.3%	73.8%/ 46.8%	90.3%/ 75.2%	
1	15.7/ 20.0	14.6/ 36.6	5.6/ 17.0	
2	7.0/ 15.6	7.6/ 10.4	3.1/ 5.8	
3	1.7/3.6	2.6/3.9	0.6/0.9	
4	1.1/2.1	1.0/1.7	0.3/0.6	
5	0.4/0.8	0.2/0.3	0.1/0.4	
6-10	- /0.4	0.1/0.3	- /0.1	
>10	- /0.2	0.1/ -	- / -	
	100%/ 100%	100%/ 100%	100%/ 100%	
11. Ground Transportation Modal Choices of Well-Wishers/ Greeters				Private automobile is the overwhelming choice of well-wishers/ greeters. First entry refers to choice of well-wishers for arrival at airport, second entry to choice of greeters for departure from airport.
Private Auto	99.1%/ 84.4%	80.0% 96.9%	81.8% 90.1%	
Car Rental Bus	0.9/6.0	- /1.5	- /0.7	
Taxi	- /5.0	6.7/0.7	9.1/4.9	
Airport Limousine	- /2.8	- /0.3	9.0/0.7	
Bus	- /1.8	6.7/0.6	- /0.8	
Other	- / -	6.6/ -	- /2.8	
	100%/ 100%	100%/ 100%	100%/ 100%	
12. Location Where Enplaning Passengers and Well-Wishers Part				Considerable variations exist among airports due in large part to differences in availability and cost of parking and in accessibility of departure gates to well-wishers.
Access Road Curb	28.5%	28.6%	41.5%	
Ticket Counter	30.4	13.2	14.3	
Security	22.0	5.9	23.4	
Gate	19.1	52.3	20.8	
	100 %	100 %	100 %	
13. Location Where Deplaning Passengers and Greeters Meet				Same situation as with item 12 above. Terminal building configuration is also an improtant factor in determining meeting location.
Egress Road Curb	36.1%	22.9%	24.3%	
Baggage Claim Area	51.9	13.5	27.8	
Security	-	2.7	1.4	
Gate	12.0	60.9	46.5	
	100 %	100 %	100 %	

TABLE 6-3. FACILITY PROCESSING CHARACTERISTICS

DATA ITEM	MIAMI INT'L	DENVER STAPLETON	NEW YORK LA GUARDIA	COMMENTS
1. Processing Time at Full-Service Ticket Counters				Processing times at full-service counters exhibit wide variability with cases in which it took up to 30 minutes to serve a single passenger.
Mean Value	3.6 min	3.0 min	3.9 min	
Standard Deviation	3.3 min	2.9 min	2.6 min	
2. Processing Time at Express Ticket Counters				In addition to being shorter, express ticket counter processing times are characterized by a narrower distribution.
Mean Value	2.3 min	2.1 min	2.0 min	
Standard Deviation	2.1 min	1.4 min	1.6 min	
3. Processing Time at Security Screening Points				Processing time is defined as the complete security clearance time, i.e., from the time the passenger gives the attendant baggage to be checked or passes through the magnetometer to the time the passenger is free to leave the security area.
Mean Value	0.49 min	0.31 min	0.46 min	
Standard Deviation	0.48 min	0.25 min	0.30 min	
4. Processing Time at Car Rental Booths				
Mean Value	5.6 min	5.4 min	4.1 min	
Standard Deviation	4.9 min	3.4 min	2.8 min	
5. Processing Time at Parking Lot Exits				
Mean Value	0.58 min	0.51 min	0.51 min	
Standard Deviation	0.44 min	0.33 min	0.35 min	

TABLE 6-3. FACILITY PROCESSING CHARACTERISTICS (Cont.)

DATA ITEM	MIAMI INT'L	DENVER STAPLETON	NEW YORK LA GUARDIA	COMMENTS
6. Dwell Time of Vehicles at Access/Egress Curb				Dwell times depend largely on degrees of enforcement of standing and parking limitations at curbs. Deplaning curb dwell times are consistently larger than at enplaning curbs.
a. Enplaning Curb				
Mean Value	2.6 min	1.9 min	1.4 min	
Standard Deviation	3.5 min	3.4 min	1.9 min	
b. Deplaning Curb				
Mean Value	3.3 min	5.7 min	3.5 min	
Standard Deviation	5.5 min	7.1 min	4.3 min	
7. Processing Time at Immigration Checks for Foreign Citizens				Based on 178 observations only; note large standard deviation implying wide spread of processing times.
Mean Value	2.28 min	No Data	Not Applicable	
Standard Deviation	2.38 min	No Data	Not Applicable	
8. Processing Time At Customs Check				Based on 479 observations at Miami International.
Mean Value	2.73 min	No Data	Not Applicable	
Standard Deviation	2.05 min	No Data	Not Applicable	
9. Processing Time at Gate Counters (Enplaning Passengers)				Based on observations of 3 flights only at Miami and 2 flights each at Denver and La Guardia; gate processing times will vary depending on equipment available to airline agents at gates and the nature of processing performed there.
Mean Value	1.84 min	0.56 min	1.25 min	
Standard Deviation	1.12 min	0.30 min	0.76 min	

7. GENERAL REFERENCES ON LANDSIDE PLANNING

General guidelines for landside design and planning are provided in the following three publications:

a. The Apron-Terminal Complex: Analysis of Concepts for Evaluation of Terminal Buildings, R.M. Parsons Company and Air Transportation Association of America, 1973 (available through National Technical Information Service, Springfield VA) [FAA Report FAA-RD-73-82].

b. The Apron and Terminal Building Planning Manual, R.M. Parsons Company (for FAA), July 1975 (available through NTIS; ADA018120).

c. Airport Terminals Reference Manual, International Air Transport Association, 5th Edition, December 1970.

The following report presents extensive discussions of all facets of airport landside capacity and places particular emphasis on the various measures of level-of-service on landside:

d. Airport Landside Capacity, Special Report 159, Transportation Research Board, National Research Council, National Academy of Sciences, Washington DC, 1975.

The following two standard references on airport planning and design contain several useful chapters on landside planning:

e. DeNeufville, R., Airport Systems Planning-A Critical Look at the Methods and Experience, MIT Press, Cambridge MA, 1976.

f. Horonjeff, R., Planning and Design of Airports, 2nd Edition, McGraw-Hill, New York NY, 1976.

g. Ashford, N./Wright, P., Airport Engineering, John Wiley, New York, NY, 1979.

Extensive bibliographies of reports and papers on specific aspects of landside planning are contained in the last three documents cited above.

The following advisory circular provides general guidelines and references to technical documents on airport master planning:

h. Airport Master Plans, AC 150/5070-6, prepared by the Airports Service, Federal Aviation Administration, U.S. Department of Transportation, February 1971.

i. Planning and Design Considerations for Airport Terminal Building Development, AC 150/5360-7, Airport Service, FAA, U.S. DOT, 1976.

APPENDIX A
DESCRIPTION OF AIRPORT LANDSIDE SIMULATION MODEL (ALSIM)*

A.1 GENERAL DESCRIPTION

The Airport Landside Simulation Model is a computer program which quantifies parameters describing flow due to the movement of people and vehicles through the airport landside. The model produces congestion statistics (queueing time, queue length and facility occupancy) by enacting the movement and processing of individual enplaning or deplaning passengers and visitors between the airport boundary and the aircraft. At the completion of a predetermined simulated time period, the required statistical information for each facility or processing station is tabulated.

This model simulates processing at the service facilities listed at the upper part of Table A-1. For each facility, ALSIM reports on numerous performance characteristics such as the number of patrons utilizing the facility, the maximum and the average number of agents (or servers) busy during the simulated time interval, the size of the queue before each facility, the time spent waiting in queue, etc. In addition, ALSIM can be asked to provide information on the flow rates and the instantaneous count of people or vehicles for all facilities including the access/egress facilities and waiting/walking areas listed in the lower part of Table A-1.

The inputs to ALSIM consist of the following four categories: (1) information related to the flight schedule; (2) description of passenger characteristics; (3) description of landside geometry at the airport of interest; (4) information on characteristics of individual facilities. A large variety of items can be specified for each category. A listing of these input items was presented in Table 6-1.

*Excerpted in large part from: "Airport Dynamic Simulation," by M. Gorstein and L. McCabe, paper delivered at Air Transportation Meeting, in Boston MA, May 1-4, 1978 (Paper No. 780516, SAE).

TABLE A-1. LANDSIDE FACILITIES SIMULATED BY ALSIM

a. Processing Facilities Simulated Ticket counters Baggage check-in counters Express check-in counters Security checkpoints Seat assignment counters Immigration clearance Customs clearance Baggage claim area Car rental counters Parking lot exits
b. Access/Egress and Waiting/Walking Areas Simulated Inbound roadway Parking lot/parking spaces Curbside Corridors/walkways Lobbies Gate (departure) lounges Outbound roadway

The landside simulation program is written in GPSS-V with an extensive FORTRAN supporting subprogram. It is constructed to utilize the advantages of both languages. GPSS is designed to describe queuing and service processes and to produce automatically summarized statistical information. FORTRAN is useful for accepting facility coordinates and flight schedule information, allowing the simulation of any airport landside configuration without program changes. FORTRAN also performs matrix searches to assign facility numbers to GPSS transactions, thereby lending efficiency to model operation.

The simulation model as shown in Figure A-1 consists of the following elements: (1) timer, (2) control, (3) facility modules, (4) enplaning passenger logic, (5) deplaning passenger logic, and (6) definitions.

The model utilizes a modular approach to simulate the various landside functions. The modules correspond to the specific attributes and operations of the facilities. Intercommunication between the modules is tightly controlled through a control section allowing the model to be flexible and easily adaptable to different airports. Modules can be easily added or removed to reflect the addition of new functions or the deletion of nonexistent facility functions at the airport under study.

Each module simulates a different process function for enplaning and deplaning passengers. The model currently performs the following:

- Creates deplaning passenger transactions and performs assignment of the attributes (number of bags, ground transportation mode, etc.) to each.
- Creates enplaning passenger transactions and performs assignment of attributes to each.
- Creates well-wisher and greeter transactions.
- Assigns transfer passengers from the arriving flights to the departing flights.

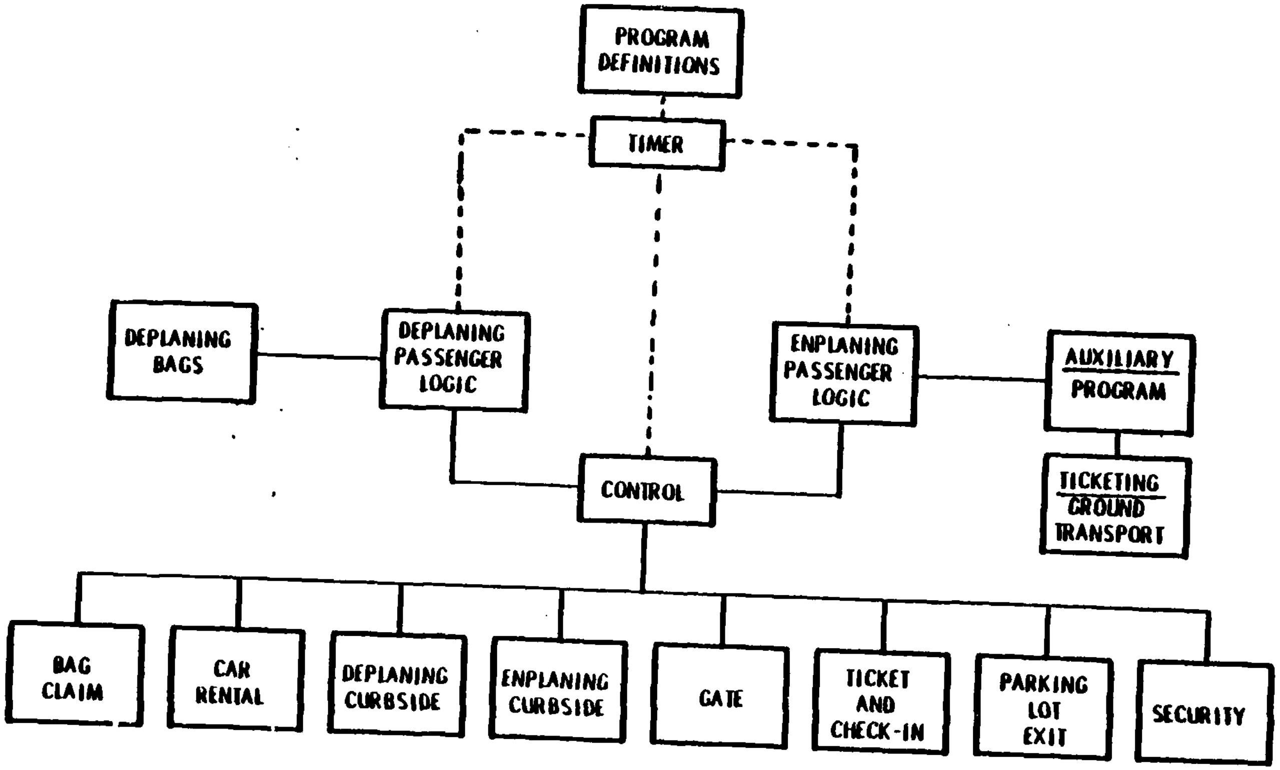

FIGURE A-1. AIRPORT LANDSIDE SIMULATION MODEL

- Produces statistics of the activities of the passengers and the vehicles at the enplaning and deplaning curbs.
- Provides counts of vehicles on inbound and outbound roadways and vehicles in parking lot.
- Simulates passenger waiting time at baggage claim.
- Simulates matching of deplaning passengers and greeters.
- Models queueing and service processes at ticket and check-in stations, customs, immigration, gate, security, car rental, and parking lot exit.

The model also has a provision to simulate transfer devices such as moving ramps, escalators, etc.

A single simulation run for a 100 gate airport during a busy period involving 20,000 passengers on 165 flights extending over three hours requires approximately 7 minutes of central processor unit (CPU) time on an IBM 370 model 158. An additional thirty seconds of CPU time is used to operate the auxiliary program prior to simulation. This program generates all of the GPSS transactions representing enplaning passenger groups and stores them for simulation entry at assigned times. For this example, one GPSS transaction is used to represent two passenger groups.

Virtual memory size required to operate the main program is 556K bytes. Due to branching instructions internal to this program, it may only be operated on the GPSS-V OS Version supported by IBM as program product 5734-XS2.

Table A-2 lists the major program areas that perform all the functions discussed above.

A.2 PROCESSING OF PASSENGERS AND VISITORS

The processing by ALSIM of enplaning, deplaning and transfer passengers and of visitors is now described briefly.

The way in which ALSIM simulates activities related to enplaning passengers is outlined in Figure A-2. Transactions

TABLE A-2. MAJOR PROGRAM AREAS

INPUT SECTION

- o Airline Flight Schedule
- o Modal Choice Data
- o Enplaning/Deplaning and Transfer Passenger Data
- o Facilities Data
- o Facilities Location, Number and Service Time Distribution

PROCESSING SECTION

- o Creates Enplaning and Deplaning Passenger Transactions & Assigns Attributes
- o Assigns Transfer Passengers to Departure Flights
- o Models Queueing & Service Processes at Facilities
- o Assigns Bag Unloading Time From Distributions and Simulates Matching of Deplaning Passengers and Bags
- o Accumulates Queue & Storage Statistics
- o Stores Periodic Flow Data at Each Facility

OUTPUT SECTION

- o Passenger Delays
- o Number of Passengers Queueing
- o Average Number of Agents Busy
- o Total Patrons Served
- o Baggage Claim, Enplaning/Deplaning Curbside Data
- o Airline Concourse & Facilities, Passenger Congestion Periodic Flow and Queue Length Data

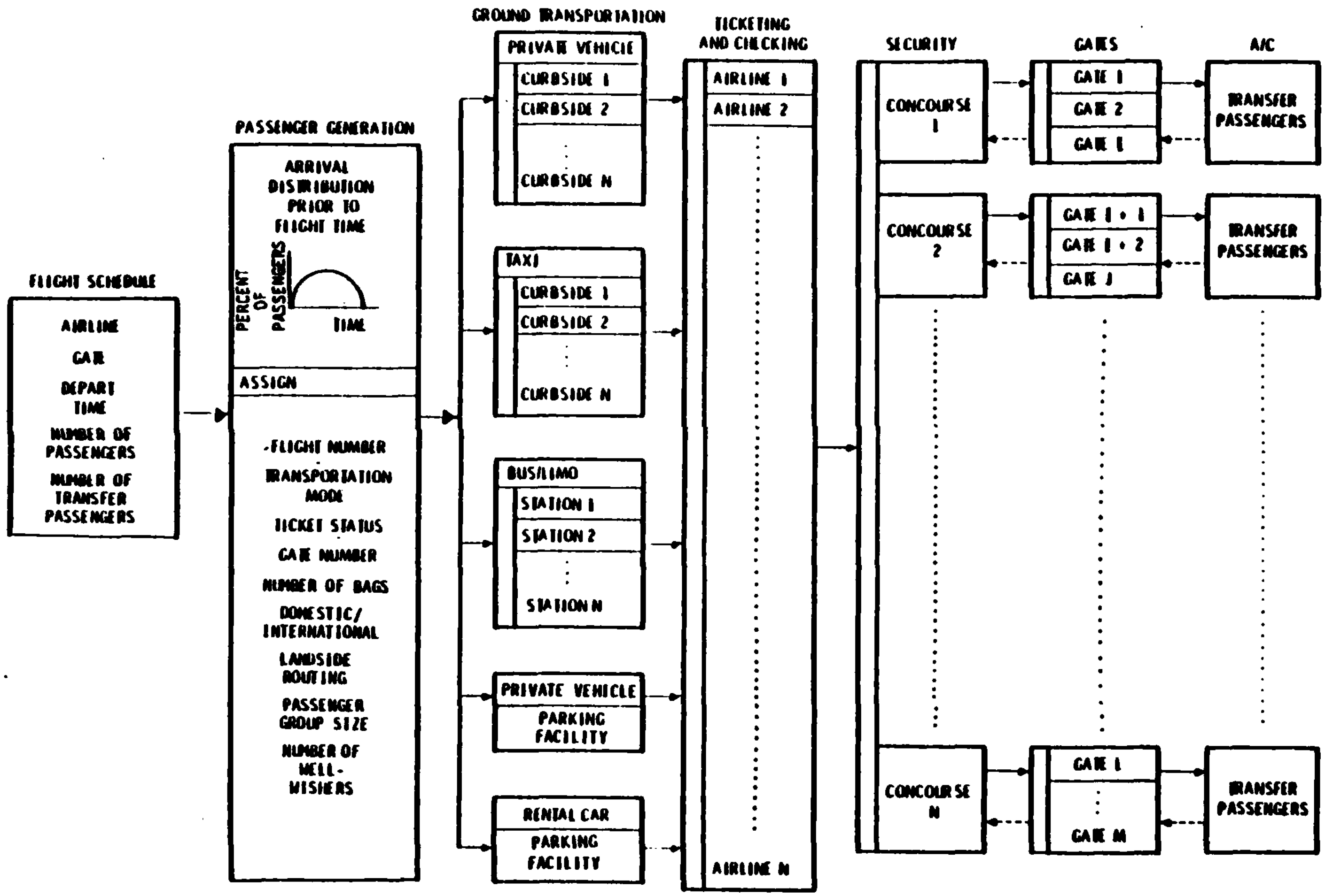

FIGURE A-2. ENPLANING PASSENGER FLOW

representing locally originating passengers are generated on a flight-by-flight basis according to the schedule and are assigned the flight number and type (domestic, international, commuter) which are carried along as GPSS transaction parameters. Other passenger characteristics are assigned using random number generation. For example, if 40 percent was input as the percentage of preticketed passengers, those transactions drawing random numbers between 0 and 399 would be assigned a ticketed status, and those with random numbers from 400 to 999 would be designated "non-ticketed." Modal choice, number of bags, number of visitors, and passenger group size are also selected by this method.

From the distribution of arrival times prior to simulation, enplaning passenger transactions are assigned a clock time to proceed to the first landside facility which is either the curb, bus station or parking garage. The earliest simulated clock time is specified as 150 minutes before the first flight.

Enplaning passengers approaching the curb are delayed by roadway congestion if double parking or queueing interferes with traffic flow. Vehicles are assigned to curbside areas dependent upon airline. Open curb spaces are first filled, then double-parking, then a limited sized queue. Those who are unsuccessful at finding a location in order of these three types of space search at the next curb area. If all specified areas are filled, the vehicle recirculates.

Passengers arriving by taxi perform the same operations as private vehicles. Buses and limousines are assumed to proceed to a station separate from the curbside. Rental car passengers proceed to the rental car parking lot.

If well-wishers are to accompany the passengers into the terminal, the car then proceeds to the parking lot. Otherwise, the car remains at the curb for an unloading time, then departs, and the outbound roadway count is incremented. The passenger group proceeds into the terminal for processing.

Passengers with baggage are sent to either a preticketed bag check or full-service counter, depending upon ticketed/non-ticketed status. A random number draw is used to assign each individual service time as the transaction enters the service storage. If all servers are occupied at a facility, the simulation establishes a queue and maintains statistics of waiting times and queue length. Preticketed passengers without baggage are routed directly to security.

Following check-in, all enplaning passengers enter security. The gate number of the passenger's flight is in a flight table matrix, and the associated security station is assigned. The passenger proceeds from security to the gate where the final processing is simulated. After this step, holdroom counts are incremented until boarding time and then zeroed at flight departure time.

Well-wishers accompanying passengers into the terminal are split off either at security or at the gate. All well-wishers proceed to the terminal exit, then to the parking garage, and depart from the airport landside.

The deplaning passenger simulation is shown in Figure A-3. Terminating and transfer passengers are generated by an arriving flight based upon numbers input for each class. Using random number draws, each terminating passenger is assigned a number of bags, ground transportation mode, gate number, passenger party size, and the number of greeters, when applicable. Greeters are also generated and assigned to proceed to the parking lot or curbside, and then to the meeting area.

After deplanement, passengers with bags proceed to bag claim. Those designated to be met by greeters at the gate are joined by them. Passengers without bags proceed to the enplaning curb if they are to be met. The others without bags either proceed to the car rental counter or leave the terminal and go to the garage, taxi stands, bus stops, or limo stations.

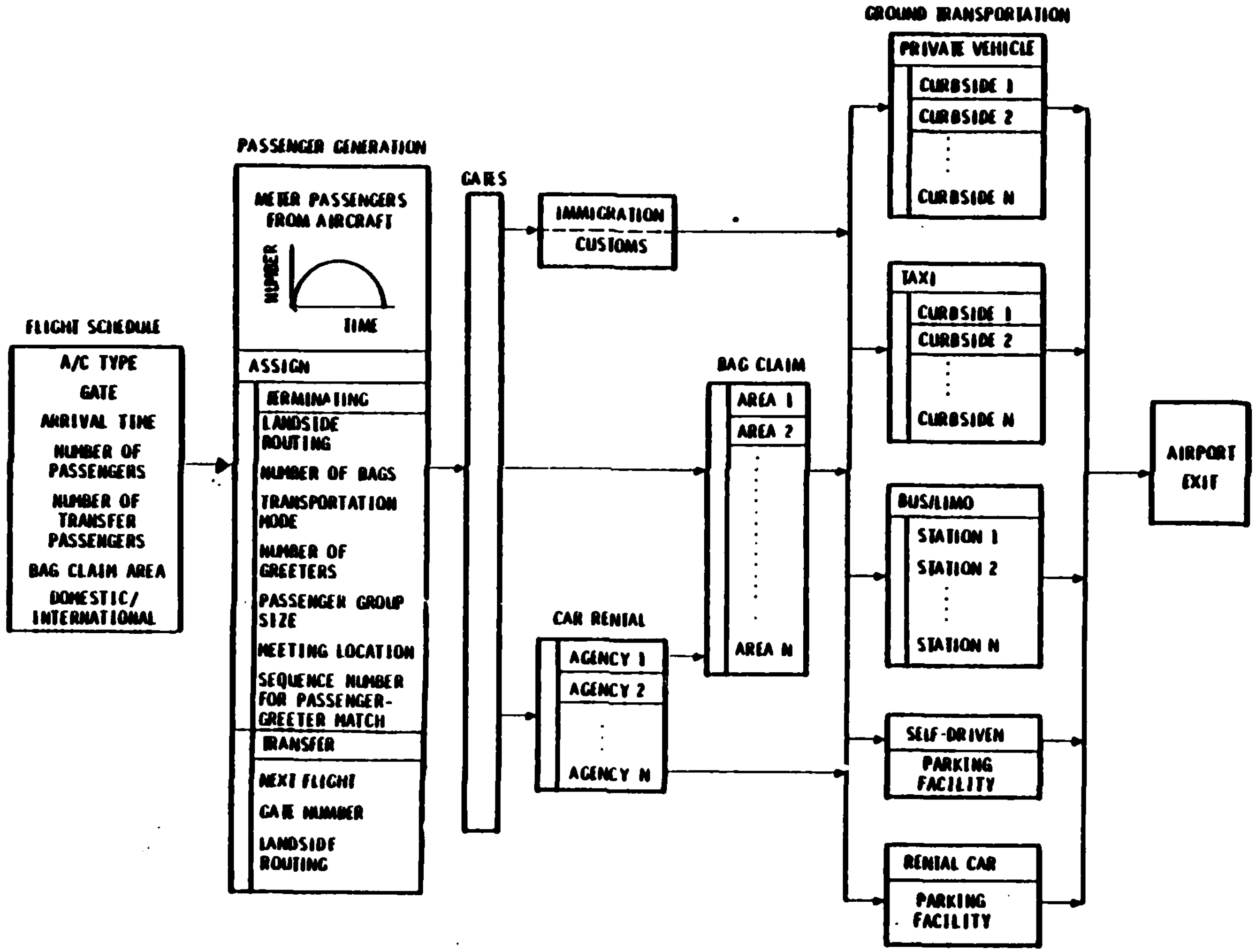

FIGURE A-3. DEPLANING PASSENGER FLOW

Greeters designated to meet arriving passengers at bag claim are joined with their parties. Waiting times to represent bag arrivals are simulated for each group. Passengers and visitors then proceed out of the terminal to ground transportation facilities.

For international flights, immigration and customs are included in the passenger routings. Service times for passport control and customs bag search are drawn from input distributions.

Transfer passengers randomly choose their next flight from a table of departures which occur between thirty minutes and two hours. Passengers obtaining flights on the same concourse are randomly selected to proceed to the next gate or out to the ticket lobby and concessions based upon input percentages. Transfer passengers with flights on other concourses stop at concessions or ticket counters or proceed directly to the security station and gate. The security and gate processing is the same as for other enplaning passengers.

International transfer passengers are processed through immigration and customs. They then proceed to the check-in counter and are thereafter simulated as originating passengers.

The number of greeters entering the terminal is calculated by taking a percentage of those terminating deplaning passengers designated to be met by private auto. This quantity is further divided into numbers of greeters meeting passengers at the gate, lobby or bag claim. From these, the greeter group transactions are generated and routing functions to proceed to the meeting locations are assigned. Group sizes are generated from an input distribution and assigned to a transaction parameter.

A distribution of times of arrival at the airport prior to arriving flight time is used to determine a starting time for the greeter to appear at the landside. Greeters proceed to the parking area or curbside and move through the terminal. The greeters and terminating passenger transactions are matched and the numbers of greeters in the group are absorbed into the passenger transaction. The party then proceeds according to the assigned deplaning passenger routing.

Vehicles without greeters entering the terminal are also generated to meet the terminating passenger at the curbside. Arrival times at the curb are selected from the distribution of arrival times prior to flight.

At the conclusion of the simulation, a statistics report is produced for each of the facilities encountered by enplaning and deplaning passengers. The output items which are of major interest are: total number of persons entering queues, maximum queue sizes, average queue sizes, average time spent waiting in the queues and the distribution densities of queueing times. Other outputs related to the service aspects of the facilities are: total number of patrons served, maximum number of agents busy, average number of agents busy and average service time per patron. Occupancies and flow values as a function of time are presented. A summary of outputs at facilities was presented in Table 3-1.

APPENDIX B
DETERMINATION OF REQUIRED SAMPLE SIZE

This appendix describes briefly one particularly useful formula for determining the required sample size in data collection efforts for ALSIM. This formula can often be applied when the aim is to obtain an estimate, $\overline{X}$, for the mean value of a single parameter X. In such a case:

$$N = \frac{z^2}{e^2} \frac{S_x^{\,2}}{\overline{X}^2} ,$$

where:

N = the required sample size

e = the confidence interval as a fraction of the sample mean value $\overline{X}$ (e.g., for a 10% confidence interval, e = 0.10)

z = the number of normal standard deviations corresponding to a given confidence level (e.g., for confidence levels of 90%, 95% and 99%, z takes the values 1.64, 1.96, and 2.58, respectively).

$\overline{X}$ = the sample mean value of X

S_X = the sample standard deviation of X.

For commonly used values of z and e (e.g., 1.96 and 0.10, respectively), the required sample size, N, for some common data items related to airport passenger characteristics range from less than 100 sample points to a few thousand. The latter applies to data items for which the samples obtained exhibit considerable variability (i.e., the ratio $S_X{}^2/\overline{X}^2$ is large). For example, such data items as passenger processing times at full service ticket counters and at customs usually exhibit wide variability and, therefore, necessitate making a large number of observations in order to obtain reliable input data for ALSIM.

APPENDIX C
DEFINING AND ESTIMATING LANDSIDE CAPACITY

C.1 INTRODUCTION

The purpose of this appendix is to present some ideas on the question of defining and measuring the capacity of landside facilities at major passenger airports.

The approach suggested here is influenced to a great extent by two considerations. First, landside airport facilities often compete for the same sources of project funding as airport facilities. The allocation of limited resources requires a method for comparing landside with airside needs. This is especially true at this particular time when a largely unforeseen quantum growth in passenger traffic is creating major congestion problems on airport access roads and in airport terminal buildings throughout the United States, and thus the need for landside investments is particularly acute.

The second consideration is that in recent years a number of analytical or simulation models of landside facilities have been developed ([PARA 77], [GENT 77]), including ALSIM. For the first time, these models have made it possible to assess quantitatively (at least in an approximate way) potential congestion problems at landside for various conceivable levels of demand. To take full advantage of the existence of these models it is again desirable to arrive at a clear understanding of such terms as "capacity" and "level of service" for the landside, as well as to recognize the capabilities and the limitations of quantitative analysis with these new tools.

In view of the above, the approach that will be described here has been designed under the dual objectives of:

- o facilitating comparisons between landside and airside operating conditions,

- being compatible with the capabilities and limitations of the best of the mathematical or computer-based landside models available today.

In what follows we first review the prevailing definitions of airside capacity and discuss their main strong and weak points and their possible applicability to landside. With that background we then define landside capacity through use of two alternative measures of passenger delay. The minimum capacity value will be used to define the landside capacity.

C.2 DEFINITION OF AIRSIDE CAPACITY

We use the term airside of an airport to mean the network of aprons, taxiways and runways through which aircraft on an airport move during the arrival and departure phases of flights.

The terms "airside capacity" and "runway(s) capacity" have come to be used almost interchangeably over the years. This is simply in recognition of the fact that runways turn out to be the "bottleneck" of the airside network in the overwhelming majority of congested airports, and consequently, that airside capacity is largely determined by runway capacity. Here, however, we shall maintain a very general level of discussion, so that "airside capacity" will explicity include taxiway, apron and gate capacity, in addition to runway capacity. Similarly, by "airside delays" we shall mean the total amount of delay incurred during the passage of an aircraft on arrival (or on departure) through the various elements of the airport airside complex.

Two different definitions of airside capacity have been prevalent to date. The first of these defines airside capacity as the average number of movements that can be conducted over an hour under continuous demand conditions and without violating ATC (and airport traffic) separation. Capacity defined in this way is also often referred to (for obvious reasons) as maximum throughput capacity, saturation capacity or maximum service rate [DOUG 76]. The use of the term "average" number of movements is in recognition of the fact that intervals between aircraft movements are not constant quantities but vary according to aircraft type, weather conditions, type of operation (arrival or departure), pilot and air traffic controller performance, etc. Thus the actual number of movements per hour, even under continuous demand conditions, can vary appreciably, and hourly capacity is defined as the average value of this actual number over a large number of observations [DOUG 76].

The second definition associates hourly airside capacity with a standard of performance vis-a-vis airside delays. Specifically, capacity is now defined as the number of movements that can be handled over an hour such that average delay to aircraft is equal to a specified threshold value. (That value is usually taken to be equal to 4 minutes for airports with mostly commercial traffic and to 2 minutes for airports serving primarily general aviation aircraft.) This capacity has come to be known as the practical hourly capacity (PHOCAP) [AIL 69].

There are several noteworthy points about the two definitions. First, and perhaps most important, is the fact that there is a fundamental (and close) relationship between maximum throughput capacity and PHOCAP. That is, given the maximum throughput capacity, a time-pattern of aircraft demand for runway use, and a threshold value for acceptable average delay per movement; it is then possible, at least in theory, to estimate PHOCAP by using an appropriate queueing model or a good simulation program. This is done by: (i) deriving a curve (such as the one shown in Figure C-1) that gives average delay as a function of the number of actual hourly movements at the airport in question, and (ii) projecting on the hourly movements axis the pre-specified threshold value for average delays in the manner shown in Figure C-1.

A second observation is that emphasis in the definitions is placed on hourly capacities. This implies that individual hours

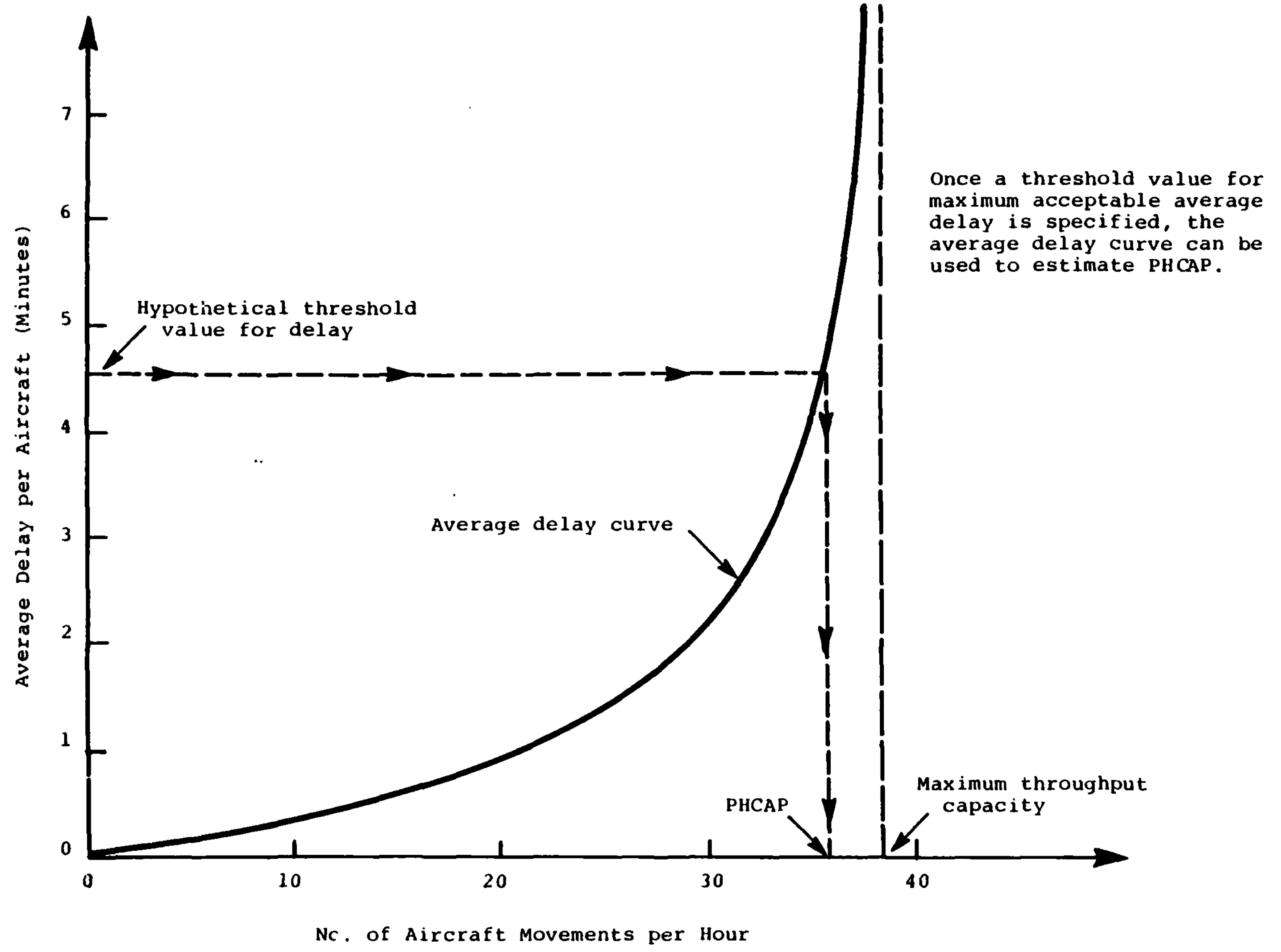

FIGURE C-1. AVERAGE DELAY VS. HOURLY TRAFFIC MOVEMENT are treated more or less as independent entities, despite the fact that, for instance, long delays during a particular hour may have serious "carry-over" effects on waiting times during subsequent hours.

A third observation is that average delay is chosen as the sole measure of level of service. While average delay is indeed a most important indicator of the cost or "inconvenience" suffered by a typical aircraft movement, it still is only an aggregate measure and does not indicate how delay is distributed among aircraft which use the airport. We shall return to this point shortly.

Both of the above definitions of capacity have their proponents and their critics. In the next section we shall review briefly the main deficiencies of each of the definitions. Indicative, however, of the controversy surrounding the existing definitions of airside capacity is the fact that the existing "official" handbooks of airport capacity issued over the last decade by the FAA are at odds in this respect. The long-standing Airport Capacity Handbook [AIL 69] advocates the use of PHOCAP whereas the newly issued Techniques for Determining Airport Airside Capacity and Delay [DOUG 76] uses exclusively the concept of maximum throughput in estimating airside capacity.

C.3 DISCUSSION OF THE DEFINITIONS OF AIRSIDE CAPACITY

Both definitions of airside capacity have been severely over the years. The most important points raised by critics of each of the two measures are the following:

With respect to maximum throughput capacity, it is often noted that this is only of theoretical interest, being of little practical value when it comes to using it as a guideline for airport planning. The reason for this is that, if indeed one attempts to process through the airport's airside, for long time intervals, a number of operations which is close to the maximum throughput capacity, delays to users will reach unacceptable levels, as shown in Figure C-1. If that is so, then the airport must be operated at demand levels less than the maximum throughput capacity. But, at those lower levels of demand, the only way to determine whether the airside network is adequate to serve traffic is to postulate some threshold value for level of service in terms of acceptable delays to aircraft. In addition to average delay as an aggregate measure of level of service of PHOCAP approach to airside capacity, one is equally interested in how delay is distributed among aircraft. Stated otherwise, most people would agree that level of service is better when all aircraft suffer approximately the same delay than when some aircraft suffer practically no delay at all while some others are delayed for very long periods of time.

C.4 APPLICATION OF CONCEPTS TO LANDSIDE CAPACITY

The preceding discussion provides the background for applying similar concepts to the definition of landside capacity. The earlier discussion is also useful in that it sets the "ground rules" for our work on landside capacity. These ground rules are basically two:

1. If we desire compatibility and comparability with airside measures of capacity, then the possible approaches to landside capacity must be restricted along the lines of maximum throughput capacity or of level-of-delay-related capacity described earlier.

2. There are inherent difficulties associated with both types of definitions which must be recognized a priori. These difficulties are essentially related to the multi-dimensionality of the problem with which we deal (e.g., aggregate vs. disaggregate measures, time-variation of demand and interdependence among distinct time periods, and theoretical vs. practical guidelines for airport planning).

Keeping these two points in mind, we now present our first major precept with regard to landside: the "maximum throughput" type of capacity definition is quite untenable in the case of landside facilities. The reasons for this statement are obvious: Whereas at airside, there is a well-defined set of rules on minimum acceptable separations between aircraft (which in turn delimit the maximum rate of flow through the airside network), only a partial set of such rules exists on landside. Flow rates on landside can indeed be varied over a quite wide range of values almost at will, as long as increases in passenger delay and deterioration of level of comfort to passengers (and the landside facility users in general) can be tolerated. As Friday evening users of Chicago O'Hare or Washington National Airports (or of London Heathrow or JFK during the summer) will unhappily attest, there is practically no limit to the possible congestion of airport terminals and to the service delays that one may suffer there. Airport users, naturally, compensate for such conditions by simply arriving at the airport earlier, to assure themselves of being at a gate by the time of their flight's departure (or arrival, in the case of greeters).

Similarly, whereas on airside the flow of airport users consists of a single type of unit (aircraft), on landside there are passengers and visitors of many types. There are complex trade-offs among the processing rates for each of these types of users (e.g., one can restrict access to visitors in order to improve the flow rate of passengers, albeit at the risk of offending airport concessionaires) and it is practically impossible to consider all possible combinations in specifying a maximum throughput capacity.

It is therefore necessary to concentrate on level-of-waiting time measures in order to have a more consistent and workable definition of landside capacity. The following paragraphs then provide an outline of our basic premises in this respect.

a) We shall define capacity in terms of level of waiting time, using both an aggregate and a distributive indicator. That is, we shall say that landside capacity has been reached when the level of waiting time has increased beyond prespecified threshold values for either one of the two indicators that we shall use.

b) While we shall identify the indicators here, we shall refrain from specifying the threshold (critical) values for them. It is assumed that it will be up to the users of the approach outlined here (and of the associated quantitative tools) to specify these threshold values according to their perception of what constitutes acceptable waiting time. "Users" in this sense potentially includes the airlines, airport managers, airport planners and federal administrators, to name but a few.

c) Our two indicators are related to total time spent queueing to receive service at all the servers or facilities that a landside user must go through. We shall call this time "total queueing time per user" and will be concerned with two indicators: average total queueing time per user and probability that total queueing time per user exceeds a critical value. The former measures level of queueing time as experienced by the typical user (aggregate measure) while the latter describes the likelihood of extreme increases in the level of queueing time for the most "unlucky" group of users. The two measures will be considered as equally important indicators of whether landside capacity has been reached.

d) In view of the above, let us define:

A = the level of demand at which the average total queueing time per landside user exceeds X minutes

B = the level of demand at which the fraction of landside users with total queueing time per user greater than Y minutes exceeds Z.

In the above definitions X, Y, and Z are constants (the prespecified threshold values) with $0.0 < Z < 1.0$ and (presumably) with $X < Y$. The latter is true because Y is supposed to indicate a very severe and serious level of queueing time -- unacceptable in all but very exceptional cases (e.g., peak hours of the year).

We shall then say that landside capacity, C, is equal to the minimum of A and B, i.e., that:

$$C = \min(A,B).$$

The specification of X, Y and Z is left up to the user of our approach.

Several comments are now in order regarding the above. In our definitions under d) we did not specify:

- o who is the "airport user"
- o what are the units of the level of demand
- o what will be the time interval over which the level of waiting time indicators will be measured
- o what servers and facilities constitute "landside."

The vagueness, in this respect, is intentional. We would like our definition to be applicable to as wide a variety of situations as possible and thus allow the user of our approach to select whichever context seems most appropriate for the case at hand. If, for instance, groundside access is under study, "users" will probably be automotive vehicles (and demand will be specified in terms of numbers of private cars, buses, taxis, etc.) and "servers and facilities" will consist of access ramps/roads, curbsides, parking lots, etc.

While the time interval to be considered has also been left unspecified, it is believed here that the hour may be the most natural unit to use. For one thing, this would be consistent with current practice on airside, as described earlier. For another, it is true that for time spans of less than an hour, many of the quantities that specify the level of demand and of service (e.g., the number of arriving and departing flights) are subject to rather wide statistical fluctuations from day to day. On the other hand, using time units longer than one hour may lead to excessive aggregation of statistics (e.g., long queueing times in a given hour followed by short queueing times in the next hour will be averaged to "medium" delays for a two-hour period, wheareas an airport passenger -- who typically is at an airport for a period between 30 and 90 minutes -- will actually experience either the one or the other condition). These comments, however, are not meant to deny the fact that choosing an hourly interval can give rise to some serious problems.

Continuing with our comments, we wish to draw attention to the fact that under paragraph c) above, we have focused our attention on total queueing time at all the facilities that a user must go through. The emphasis on "total" implies that we are more concerned here with the performance of the landside complex as a whole (whatever that complex is defined to be) as opposed to its individual parts. While in taking corrective measures (once the level of queueing time has exceeded acceptable thresholds according to our definition of capacity), one would have to examine what happens at each service facility, our point of view here is a more macroscopic one.

As for the meaning of the words "user must go through" in our definition, our concern here is with level of queueing time as it relates to the main functional purposes of landside (i.e., getting on an airplane -- or off one -- in a comfortable and expeditious manner). Thus, we are not overly concerned here with such "optional" facilities as restaurants, shopping malls, etc., which often exist in great abundance at airport landsides.

Finally, this section must be concluded with a statement of some important caveats. The approach outlined above develops some terminology for landside capacity which is oriented toward quantitative assessment (using existing tools) and toward comparison with airside capacity (using commensurate standards of performance). However, it should be fully emphasized that our definition of capacity (by means of an aggregate and a distributive indicator of queueing time) is concerned with only one of the many aspects of the adequacy of landside facilities. We believe that most airport planners would agree that queueing times of landside users are probably the most important indicator of the adequacy of landside facilities, reflecting at the same time on such other characteristics as crowdedness, the psychological and mental state of airport users and airport employees, the airport's reputation, etc. On the other hand, "adequacy and comfort" are truly multidimensional qualities, and to fully describe them a long array of indicators -- many of which are qualitative and non-quantifiable -- must be devised. Two discussions of such indicators have been presented by Brink and Maddison [BRIN 75] and by McCabe and Carberry [MCAA 75]. Stated differently, within the more global perspectives offered by these two papers, the approach presented here is intended as a contribution to the more modest goal of balanced airside-landside planning and development (see also [HOM 75]).

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FOR
APPENDIX C

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APPENDIX D

IMPORTANT APPLICATIONS OF AIRPORT LANDSIDE SIMULATION MODEL (ALSIM)

This appendix discusses two types of applications of ALSIM: analysis of landside capacities and cost/benefit analysis of landside investments. Most of the questions that an airport planner or airport operator is likely to face (see, for instance, Section 5) can be considered as addressing aspects of either the capacity or the cost/benefit (or cost-effectiveness) issues discussed below.

D.1 Landside Capacity Analysis

The time spent waiting to receive service at the various landside facilities is an important aspect of the quality of service at an airport as perceived by landside users. A natural question to ask with regard to any specific landside facility or to any group of facilities (including the whole landside complex) concerns the maximum number of facility users that can be processed per unit of time without time-spent-queueing exceeding some prespecified threshold values. Such a number can be viewed as the capacity of that facility (or group of facilities). It will be said here that the capacity of a landside facility (or facilities) has been reached when the level of queueing time at this facility has exceeded some prespecified threshold value.

Having defined capacity and outlined the approach in Appendix C, we can now proceed to a somewhat more detailed discussion of the quantities involved and the steps required to compute them.

To do this, we shall assume that, with reference to our definition of the preceding section, we have decided what type of landside user we wish to focus on, and have identified all the landside servers or facilities that these users must go through. (There is nothing restrictive about these assumptions, as will become clear later in this section.) For instance, the users could be enplaning passengers in which case the sequence of servers and facilities that they will have to go through is roughly shown in Figure D-1.

Let us now index the servers of interest sequentially with the numbers 1 through N. Suppose that the rate at which prospective users of the type on which we focus arrive at landside at an average rate of ϕ users per unit of time and suppose that the network of servers under consideration has been operating for sufficiently long, so that a long-term equilibrium condition has been reached (i.e., the effects of the "starting conditions" at the network of servers have died down). Let us now define:

w_i = the queueing time experienced by a user picked at random at server i (i = 1, 2, ..., N).

Here queueing time is defined as the time spent waiting to be serviced and does not include time in service. Thus w_i is a random variable that can take non-negative values including zero (for the case where a user immediately obtains service upon arrival at a facility). We can now define:

$w = \sum_{i=i}^{N} w_i$ = total time spent queueing by a random user at all the servers that the landside user must go to (w is also a random variable).

We then, according to our definition of landside capacity, are interested in the following two quantities:

$E(w)$ = the expected value of w, i.e., the average total queueing time per user, and

$Pr(w > Y)$ = the probability that the total queueing time of a user will exceed a specific constant threshold value of Y time units.

If we denote the cumulative probability distribution of random variable w as $F_w(w_0)$ (= $Pr(w \leq w_0)$, where w_o is a constant), it is then clear that:

$$Pr(w > Y) = 1 - F_w(Y).$$

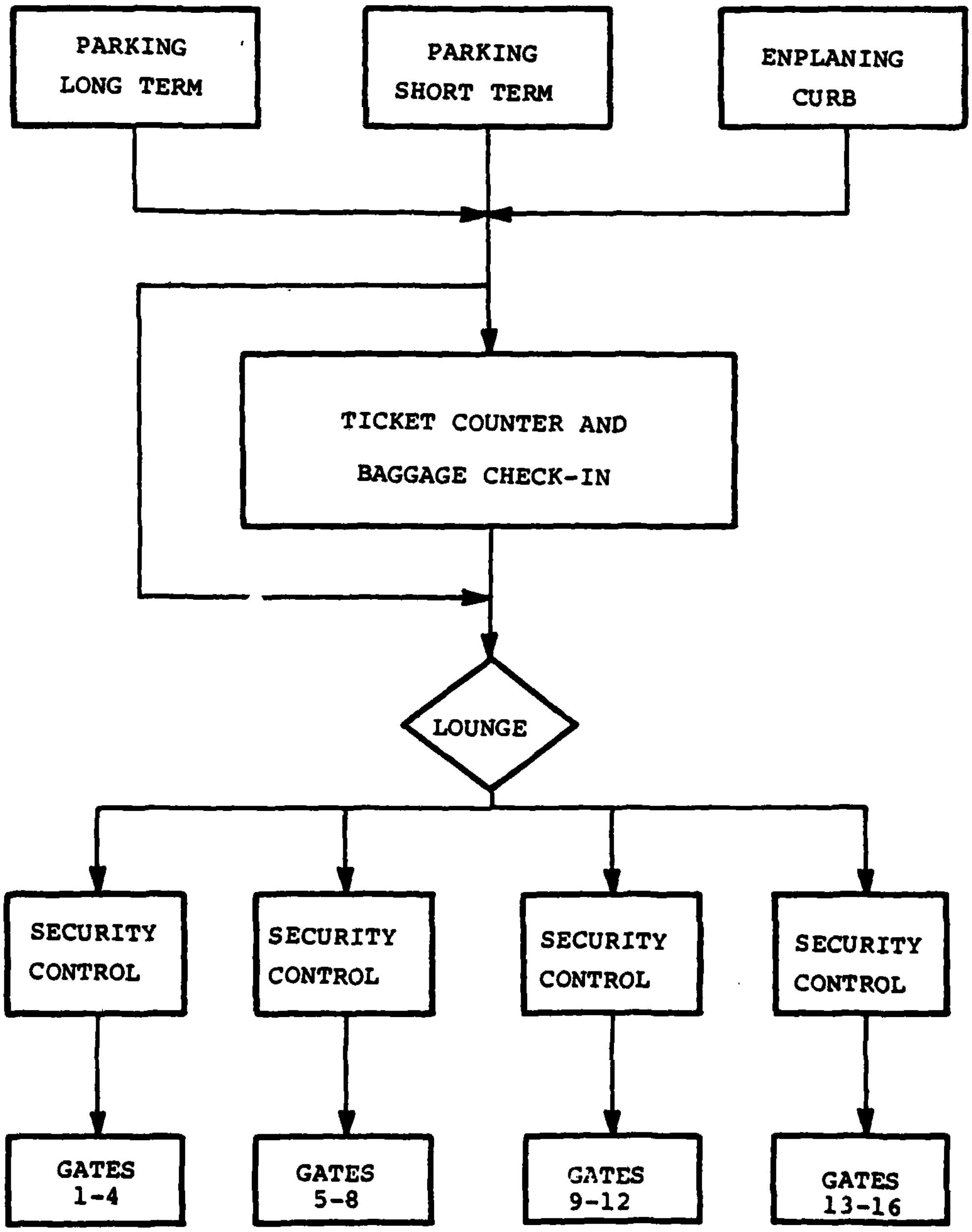

FIGURE D-1. GENERIC FLOW OF ENPLANING PASSENGERS FOR TYPICAL LANDSIDE COMPLEX

According to our definition of capacity we are thus interested in obtaining plots of the quantities $E(w)$ and $1 - F_w(Y)$ -- for some given value of Y -- as functions of the average flow rates of users through landside, ϕ. This can be accomplished through data gathering at the airport of interest or through a good simulation program or queueing theory model.

We can illustrate the above with reference to the Landside Simulation Model in which we are especially interested here. One of the outputs of this model is the average value of the recorded total waiting times at the network of servers for all the transactions processed by the model during the simulated period. Similarly, another output of this model is a histogram of the distribution of total queueing times for all the transactions processed. For a sufficiently large number of transactions, we can use the average value as an estimator of $E(w)$ and the histogram to estimate the quantity $1 - F_w(Y)$ for any given value of Y. We would then end up with plots such as the ones shown in Figures D-2 and D-3. The user of our approach could then select the values of X, Y and Z that are found appropriate and from those infer the capacity of the landside network of servers. For instance, if the user specifies X = 10 minutes, (this is the average waiting time threshold), Y = 30 minutes, and Z = 0.10 (i.e., we wish no more than 10 percent of users to wait a total of more than 30 minutes for service), then for the hypothetical case shown in Figures D-2 and D-3, it can be seen that: the landside capacity according to the average total queueing time criterion is about 1,000 users per hour; according to the distributive criterion is about 1,100 per hour; and, thus, according to our overall definition is equal to min(1000, 1100) = 1,000 users per hour. Note as well, that in Figure D-2, we have suggested several curves (one for each distinct value of Y) so that a user has the freedom to specify the values of both Y and Z as deemed appropriate.

Finally, as we have already remarked, this approach is not limited to dealing with only a single type of landside user; i.e., with a group whose members all visit exactly the same set of

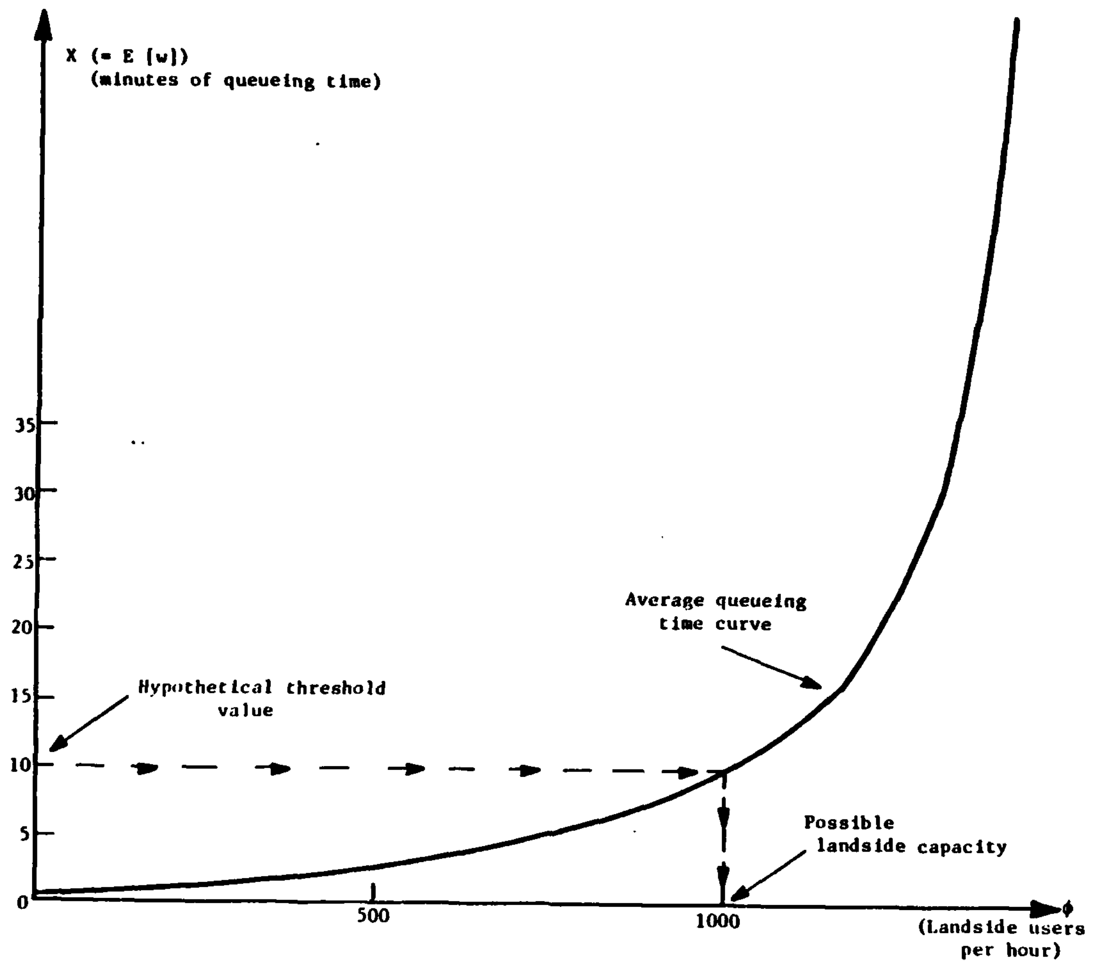

FIGURE D-2. AVERAGE QUEUEING TIME ON LANDSIDE VS. NUMBER OF LANDSIDE USERS/HOUR

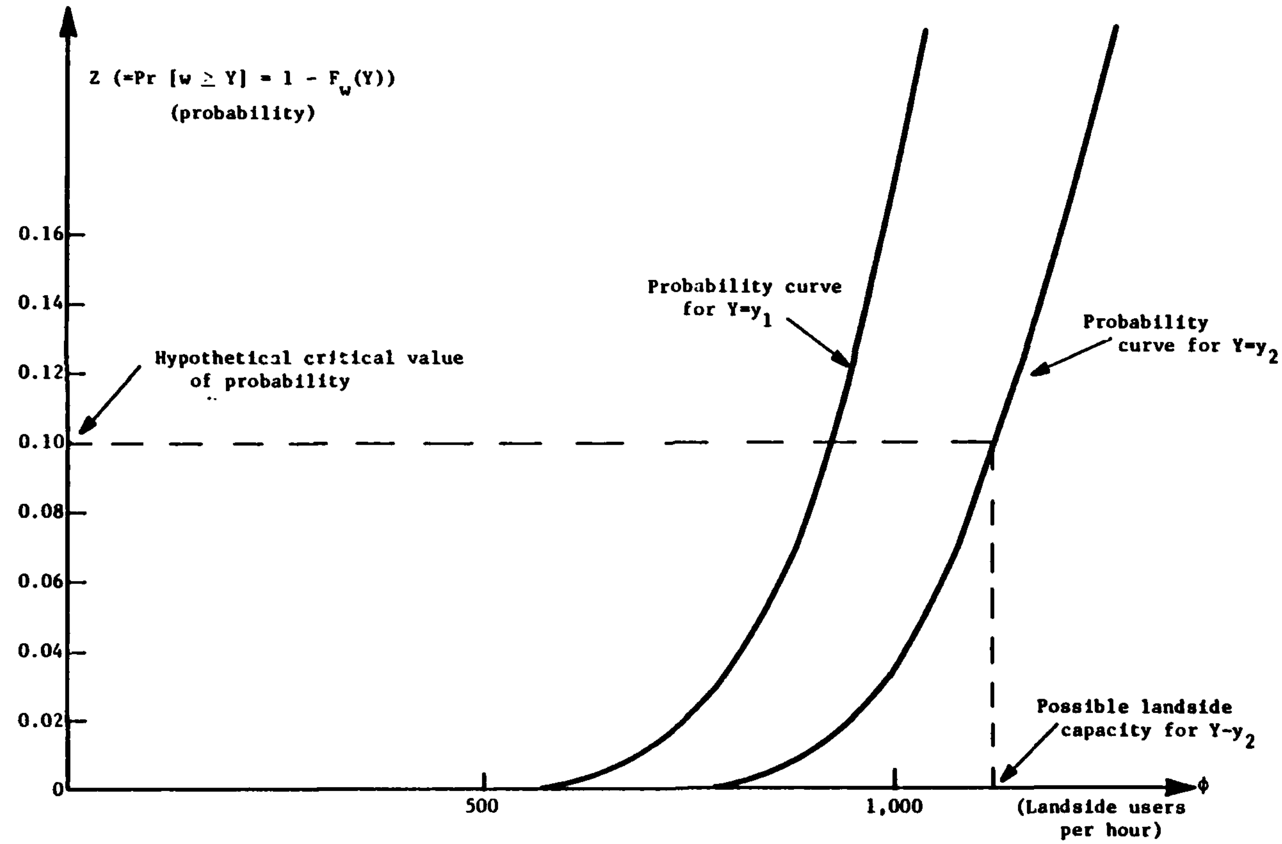

FIGURE D-3. PLOT OF THE PROBABILITY THAT A LANDSIDE USER WILL SUFFER A QUEUEING TIME WHICH IS GREATER THAN OR EQUAL TO Y MINUTES. (PLOTTED FOR TWO DIFFERENT VALUES OF Y, y_1 AND y_2)

landside servers and facilities. Instead, we can work with the same capacity concept, as it applies to several distinct groups of landside users simultaneously, by first deriving $E(w)$ and $1 - F_w(Y)$ for each group separately and then by computing the overall indicators for the combined group by multiplying with appropriate weights. For instance, should our "users" be enplaning, deplaning and transfer passengers we would have:

$$E(w) = f_E E(w_E) + f_D E(w_D) + f_T E(w_T) \quad ,$$

where f indicates a fraction ($0.0 \leq f \leq 1.0$, $f_E + f_D + f_T = 1.0$) and the subscripts E, D, and T stand for "enplaning," "deplaning" and "transfer," respectively. Similarly, if all users in a group do not pass through all servers in a network of servers but instead may skip some of them with a certain probability (e.g., some enplaning passengers do not pass thrugh ticket counters or through baggage check-in), it is again easy to make adjustments through "weighting" by the appropriate probabilities.

D.2 Cost/Benefit Analysis of Landside Investments

The addition of new equipment on landside (or the replacement of existing equipment), the construction of new facilities (or the expansion of existing ones) and the hiring of additional airport personnel often must be justified through performance of a cost/benefit analysis. Such an analysis may be required in support of applications by local airport authorities for Federal ADAP funds. Finally, in allocating the annual capital budget at each airport, it is advisable to perform a cost/benefit analysis to compare the merits of the various alternatives for investment.

The general rule in such cases is to select that course of action which maximizes the difference between incremental benefits and incremental costs that will result from such action. In practice, this is not easy to do since many types of costs and benefits on landside are difficult (or impossible) to quantify, as has already been noted in Section 4. The analyst or the planner should, however, make every effort to identify as many of such costs and benefits as possible and to describe them fully and, wherever possible, in quantitative terms.

Probably the most important type of costs and benefits to be considered in this process are economic ones. While it is relatively straightforward to estimate the economic costs of investments in new landside facilities, equipment and additional personnel, the economic benefits for airport landside must be computed in a more complicated way. The primary such benefit is the time saving to airport users that result from increased processing rates, decreased walking distances, etc., due to the contemplated improvements. It is necessary, therefore, to estimate first what these savings are (usually in terms of "annual passenger hours" or "annual passenger minutes") and to subsequently multiply this figure by the average dollar value of time for landside users.

It is with respect to estimation of time savings that ALSIM can be most valuable in the above process. Running ALSIM "before" (i.e., without the contemplated improvements) and "after" (with the improvements) will provide an immediate estimate of time savings to those involved. It should be noted that these computer runs should be performed for every year in the "lifetime" of the improvement project being contemplated because of the fact that the forecasted demand for use of landside facilities will likely change (increase) from year to year.

Once the costs and benefits for each of the years involved have been estimated and listed, the Net Present Value (NPV) of the investment under consideration should be calculated in the manner described below. NPV is defined by: NPV = (Present worth of benefits) - (Present worth of costs).

If the choice among candidate investments is to be made on purely economic grounds, the following rules provide the guidelines for making this choice*:

*See, for instance, de Neufville, R. and J. Stafford, Systems Analysis for Engineers and Managers, McGraw-Hill, New York NY, 1972, or Sassone, D., Cost-Benefit Analysis, Academic Press, New York NY, 1978.

Case 1: Only one alternative is being considered (a "yes" or "no" decision) without any budget restrictions: Approve the investment if NPV > 0 for it.

Case 2: Only one alternative is being considered, with a budget restriction: Approve the investment if NPV > 0 and the budget is not exceeded.

Case 3: Several alternatives are being compared and one of them must be chosen: In the absence of a budget restriction, select the alternative with the largest NPV provided that NPV is greater than 0; if a budget restriction exists, select the alternative with the largest NPV (provided NPV > 0) from among those which do not exceed the budget.

Case 4: Several alternatives are being compared and any combination of those can be chosen: In the absence of a budget restriction, approve all those with NPV > 0; in the presence of a budget restriction choose that combination whose total NPV is the largest possible (provided that total NPV > 0) subject to the total investment not exceeding the budget.

Example: The last case, with a budget restriction, can be illustrated as follows: Suppose that the alternatives listed in Table D-1 are being considered for increasing the processing rates at the security checkpoints at Wing A and/or Wing B of an airport terminal. For a budget allocation of $100,000, alternatives 1 and 3 should be selected. However, for a budget allocation of $85,000, alternative 2 only should be selected.

Computing the Net Present Value of Landside Investments

In performing a cost/benefit analysis of investments in additional landside equipment or facilities, the following steps should be followed to compute their Net Present Value:

i) Determine the lifetime of the investment and select the discount rate which is appropriate for this case.

ii) Estimate the costs and benefits that will result from the investment for every year of the investment's lifetime, including the initial costs and final salvage value (if any).

TABLE D-1. HYPOTHETICAL EXAMPLE COMPARING FOUR ALTERNATIVE INVESTMENTS IN IMPROVED SECURITY SERVICE

NUMBER OF ALTERNATIVE	DESCRIPTION	INVESTMENT REQUIRED	NPV
1	Add one X-ray machine at Wing A	$50,000	$52,000
2	Add two X-ray machines at Wing A	$80,000	$70,000
3	Add one X-ray machine at Wing B	$40,000	$30,000
4	Add two X-ray machines at Wing B	$70,000	$45,000

iii) Compute the net present value (NPV) associated with this investment, by multiplying costs and benefits by the appropriate discount factors and subtracting the Present Worth of the costs from the Present Worth of the benefits.

The lifetime of equipment or facilities in step i) is the number of years used to depreciate fully that type of equipment or facility. Table D-2 shows the range of values often used for some particular types of landside equipment. (Full depreciation of a piece of equipment or of a facility does not, of course, mean that this equipment or facility will necessarily be of no value or use at the end of that period.)

The discount rate currently in use by the Federal government in the United States is 10% in constant prices. In the case of airports which are often run by city-owned or state-owned Authorities, it can be reasonably surmised that the discount rate will usually be somewhat less than that used by the Federal government. In any event, each individual Airport Authority can be expected to have determined internally the discount rate to be used in evaluating capital investments.

Step (ii) of the procedure outlined above is by far the most difficult of the three - particularly with respect to the estimation of benefits for each year involved. Since the discount rates in use almost always assume constant prices (as mentioned above) annual costs and benefits should be estimated in constant prices as well (i.e., without an inflation component).

As noted earlier in this appendix, for landside the most important quantifiable benefits that result from investments in new equipment or facilities are (usually) the reductions in passenger waiting and processing times. It is in this respect that ALSIM can be particularly helpful, since it can be used to determine what these reductions are for each year under consideration.

The final step (calculation of NPV) in the recommended procedure is straightforward and, as noted, consists simply of multiplying the estimated costs and benefits by the appropriate

TABLE D-2. TYPICAL LIFETIMES OF LANDSIDE EQUIPMENT AND FACILITIES

TYPE OF EQUIPMENT	LIFETIME
X-ray machines (security)	3-5 years
Baggage-claim carousels	5-8 years
Escalators, elevators	5-8 years
Constructed facilities	10-15 years

discount factors. These factors, in turn, can be found in tables included in numerous publications* or can be computed directly through use of a pocket electronic calculator. The example in Table D-3 illustrates the above material.

*See, for instance, Standard Mathematical Tables, published by the Chemical Rubber Co. or any standard engineering economy textbook.

TABLE D-3. CALCULATIONS FOR COST/BENEFIT ANALYSIS EXAMPLE

	COST (COST) x (8% DISCOUNT FACTOR)	BENEFIT (MINUTES SAVED) x (.20) x (8% DISCOUNT FACTOR)
Now	50,000 x 1.0 = 50,000	
Year 1	30,000 x 0.926 = 27,780	200,000 x 0.20 x 0.926 = 37,040
Year 2	30,000 x 0.857 = 25,710	230,000 x 0.20 x 0.857 = 39,422
Year 3	30,000 x 0.794 = 23,820	270,000 x 0.20 x 0.794 = 42,876
Year 4	30,000 x 0.735 = 22,050	330,000 x 0.20 x 0.735 = 48,510
Year 5	30,000 x 0.681 = 20,430	400,000 x 0.20 x 0.681 = 54,480
TOTALS	Present worth of costs = $169,790	Present worth of benefits = $222,328